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GEORGE C. MARSHALL

**SPACE
FLIGHT
CENTER**

HUNTSVILLE, ALABAMA

**ORBITAL PARAMETERS FOR ARTIFICIAL EARTH
SATELLITES UP TO 40,000 KM ALTITUDE**

By

Walter H. Stafford ,
Sam H. Harlin, *sd*
Carmen R. Catalfamo *29 aug. 1963 regis*

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ABSTRACT

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Author

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FLIGHT OPERATIONS SECTION
ADVANCED FLIGHT SYSTEMS BRANCH
PROPULSION AND VEHICLE ENGINEERING DIVISION

TABLE OF CONTENTS

	Page
SUMMARY	1
INTRODUCTION.	1
DISCUSSION	1
ILLUSTRATIONS	
SECTION A	5
SECTION B	77
BIBLIOGRAPHY.	139

LIST OF ILLUSTRATIONS

Figure	Title	Page
SECTION A		
1	Geometry of the Orbital Parameters	6
2	Velocity Versus Pericenter Altitude with Apocenter Altitude for Pericenter Velocities and Apocenter Altitude for Apocenter Velocities as Parameters	
	a. Pericenter and Apocenter Altitude Range of 0 to 400 km	7
	b. Pericenter and Apocenter Altitude Range of 0 to 2,000 km.	9
	c. Pericenter and Apocenter Altitude Range of 0 to 10,000 km	11
	d. Pericenter and Apocenter Altitude Range of 10,000 to 20,000 km	13
	e. Pericenter and Apocenter Altitude Range of 20,000 to 30,000 km	15
	f. Pericenter and Apocenter Altitude Range of 30,000 to 40,000 km	17
	g. Pericenter and Apocenter Altitude Range of 34,000 to 38,000 km	19
3	Velocity to Enter Transfer Ellipse Versus Circular Orbit Altitude with Apocenter Altitude as a Parameter	
	a. Circular Orbit Altitude Range of 0 to 400 km .	21
	b. Circular Orbit Altitude Range of 0 to 2,000 km	23
	c. Circular Orbit Altitude Range of 0 to 10,000 km.	25

LIST OF ILLUSTRATIONS (Continued)

Figure	Title	Page
	b. Pericenter and Apocenter Altitude Range of 0 to 2,000 km.	51
	c. Pericenter and Apocenter Altitude Range of 0 to 10,000 km.	53
	d. Pericenter and Apocenter Altitude Range of 10,000 to 20,000 km.	55
	e. Pericenter and Apocenter Altitude Range of 20,000 to 30,000 km.	57
	f. Pericenter and Apocenter Altitude Range of 30,000 to 40,000 km.	59
	g. Pericenter and Apocenter Altitude Range of 34,000 to 38,000 km.	61
6	Eccentricity Versus Pericenter Altitude with Apocenter Altitude as a Parameter	
	a. Pericenter and Apocenter Altitude Range of 0 to 400 km.	63
	b. Pericenter and Apocenter Altitude Range of 0 to 2,000 km.	65
	c. Pericenter and Apocenter Altitude Range of 0 to 10,000 km.	67
	d. Pericenter and Apocenter Altitude Range of 10,000 to 20,000 km.	69
	e. Pericenter and Apocenter Altitude Range of 20,000 to 30,000 km.	71
	f. Pericenter and Apocenter Altitude Range of 30,000 to 40,000 km.	73
	g. Pericenter and Apocenter Altitude Range of 34,000 to 38,000 km.	75

LIST OF ILLUSTRATIONS (Continued)

Figure	Title	Page
	d. Circular Orbit Altitude Range of 10,000 to 20,000 km	27
	e. Circular Orbit Altitude Range of 20,000 to 30,000 km	29
	f. Circular Orbit Altitude Range of 30,000 to 40,000 km	31
	g. Circular Orbit Altitude Range of 34,000 to 38,000 km	33
4	Orbital Period Versus Pericenter Altitude with Apocenter Altitude as a Parameter	
	a. Pericenter Altitude Range of 0 to 400 km. . . .	35
	b. Pericenter Altitude Range of 0 to 2,000 km . .	37
	c. Pericenter Altitude Range of 0 to 10,000 km .	39
	d. Pericenter Altitude Range of 10,000 to 20,000 km.	41
	e. Pericenter Altitude Range of 20,000 to 30,000 km.	43
	f. Pericenter Altitude Range of 30,000 to 40,000 km.	45
	g. Pericenter Altitude Range of 34,000 to 38,000 km.	47
5	Semi-Major Axis Versus Pericenter Altitude with Apocenter Altitude as a Parameter	
	a. Pericenter and Apocenter Altitude Range of 0 to 400 km	49

LIST OF ILLUSTRATIONS (Continued)

Figure	Title	Page
SECTION B		
1	Velocity Versus Pericenter Altitude with Apocenter Altitude for Pericenter Velocities and Apocenter Altitude for Apocenter Velocities as Parameters	
	a. Apocenter Altitude Range of 1,000 to 10,000 km.	79
	b. Apocenter Altitude Range of 10,000 to 20,000 km.	81
	c. Apocenter Altitude Range of 20,000 to 30,000 km.	83
	d. Apocenter Altitude Range of 30,000 to 40,000 km.	85
	e. Apocenter Altitude Range of 34,000 to 38,000 km.	87
2	Velocity Required for Transfer from a Circular to an Eccentric Orbit Versus Circular Orbit Altitude with Apocenter Altitude as a Parameter	
	a. Apocenter Altitude Range of 1,000 to 10,000 km.	89
	b. Apocenter Altitude Range of 10,000 to 20,000 km.	91
	c. Apocenter Altitude Range of 20,000 to 30,000 km.	93
	d. Apocenter Altitude Range of 30,000 to 40,000 km.	95
	e. Apocenter Altitude Range of 34,000 to 38,000 km.	97

LIST OF ILLUSTRATIONS (Continued)

Figure	Title	Page
3	Orbital Period Versus Pericenter Altitude with Apocenter Altitude as a Parameter	
	a. Apocenter Altitude Range of 1,000 to 10,000 km.	99
	b. Apocenter Altitude Range of 10,000 to 20,000 km.	101
	c. Apocenter Altitude Range of 20,000 to 30,000 km.	103
	d. Apocenter Altitude Range of 30,000 to 40,000 km.	105
	e. Apocenter Altitude Range of 34,000 to 38,000 km.	107
4	Eccentricity Versus Pericenter Altitude with Apocenter Altitude as a Parameter	
	a. Apocenter Altitude Range of 1,000 to 10,000 km.	109
	b. Apocenter Altitude Range of 10,000 to 20,000 km.	111
	c. Apocenter Altitude Range of 20,000 to 30,000 km.	113
	d. Apocenter Altitude Range of 30,000 to 40,000 km.	115
	e. Apocenter Altitude Range of 34,000 to 38,000 km.	117

LIST OF ILLUSTRATIONS (Concluded)

Figure	Title	Page
5	Semi-Major Axis Versus Pericenter Altitude with Apocenter Altitude as a Parameter	
	a. Apocenter Altitude Range of 1,000 to 10,000 km.	119
	b. Apocenter Altitude Range of 10,000 to 20,000 km.	121
	c. Apocenter Altitude Range of 20,000 to 30,000 km.	123
	d. Apocenter Altitude Range of 30,000 to 40,000 km.	125
	e. Apocenter Altitude Range of 34,000 to 38,000 km.	127
6	The Characteristic Velocity Required for Circularization Versus Circularization Altitude with Pericenter Altitude of the Transfer Ellipse as a Parameter	
	a. Circularization Altitude Range of 0 to 10,000 km.	129
	b. Circularization Altitude Range of 10,000 to 20,000 km.	131
	c. Circularization Altitude Range of 20,000 to 30,000 km.	133
	d. Circularization Altitude Range of 30,000 to 40,000 km.	135
	e. Circularization Altitude Range of 34,000 to 38,000 km.	137

DEFINITION OF SYMBOLS

Symbol	Definition
a	Semi-major axis, km
b	Semi-minor axis, km
e	Eccentricity
h_a	Apocenter altitude, km
h_k	Circular orbital altitude, km
h_p	Pericenter altitude, km
p	Parameter
r_a	Apocenter radius, km
r_e	Equatorial radius, 6378.27 km
r_k	Circular orbital radius, km
r_p	Pericenter radius, km
P	Orbital period, min
V_a	Apocenter velocity, km/sec
V_k	Circular orbital velocity, km/sec
V_p	Pericenter velocity, km/sec
ΔV	Characteristic velocity, km/sec
μ	Earth gravitational constant, $398,606.6 \text{ km}^3/\text{sec}^2$

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SUMMARY

Data were generated to assist in the initial sizing of vehicles for lunar and interplanetary missions. Section A is a series of graphs concerning circular orbits from 0 to 40,000 km altitude. Section B is a series of graphs for transfer from circular orbits of 0 to 400 km altitude to other circular orbits of altitudes up to 40,000 km altitude. The velocity required to enter a given transfer ellipse and also the velocity required to circularize at apogee of the transfer ellipse are given.

INTRODUCTION

A series of graphs of various orbital elements about the earth for orbits of 0 to 40,000 km altitude is presented in this report. The velocity required to enter a transfer ellipse can be readily determined, also, the velocity required to circularize at apocenter of the transfer ellipse. These data will assist in determining the capability required for a vehicle to accomplish an earth mission, and a lunar or interplanetary mission via Earth Orbit Rendezvous Mode.

DISCUSSION

A series of graphs of various orbital elements about the earth for orbits from 0 to 40,000 km altitude is presented in this report. The data is divided into two distinct categories: Section A is a series of

graphs for circular orbits from 0 to 40,000 km altitude; Section B is a series of graphs for eccentric orbits with pericenter altitude lying in the 0 to 400 km altitude range and whose apocenter altitude lies in the 1,000 to 40,000 km altitude range.

The total velocity required to transfer from one circular orbit to another circular orbit (Figure 1) is given in two parts: part one is the transfer velocity, i. e., the difference between the initial circular orbit velocity and the pericenter velocity of the transfer ellipse; part two is the circularization velocity, i. e., the difference between the apocenter velocity of the transfer ellipse and the velocity of the final circular orbit. The addition of parts one and two then will give the total velocity increment needed for the maneuver.

The data were computed using the following equations:

Semi-major axis

$$a = \frac{r_p}{1 - e} = \frac{r_a}{1 + e} \quad (1)$$

Eccentricity

$$e = \frac{\frac{r_a}{a} - \frac{r_p}{a}}{\frac{r_a}{a} + \frac{r_p}{a}} = \frac{V_p - V_a}{V_p + V_a} \quad (2)$$

For evaluation of the parameter

$$p = a(1 - e^2) = r_p(1 + e) \quad (3)$$

Apocenter radius (distance from focus to apocenter)

$$r_a = a(1 + e) = \frac{p}{1 - e} \quad (4)$$

Pericenter radius (distance from focus to pericenter)

$$r_p = a(1 - e) = \frac{p}{1 + e} \quad (5)$$

Orbital period

$$P = 2\pi \sqrt{\frac{a^3}{\mu}} = 2\pi \sqrt{\frac{r_a^3}{\mu(1+e)^3}} \quad (6)$$

For evaluation of speed at apocenter

$$V_a = \sqrt{\left(\frac{\mu}{a}\right) \left(\frac{1-e}{1+e}\right)} = \sqrt{\left(\frac{\mu}{r_a}\right) (1-e)} \quad (7)$$

For evaluation of speed at pericenter

$$V_p = \sqrt{\left(\frac{\mu}{a}\right) \left(\frac{1+e}{1-e}\right)} = \sqrt{\left(\frac{\mu}{r_p}\right) (1+e)} \quad (8)$$

ILLUSTRATIONS

SECTION A

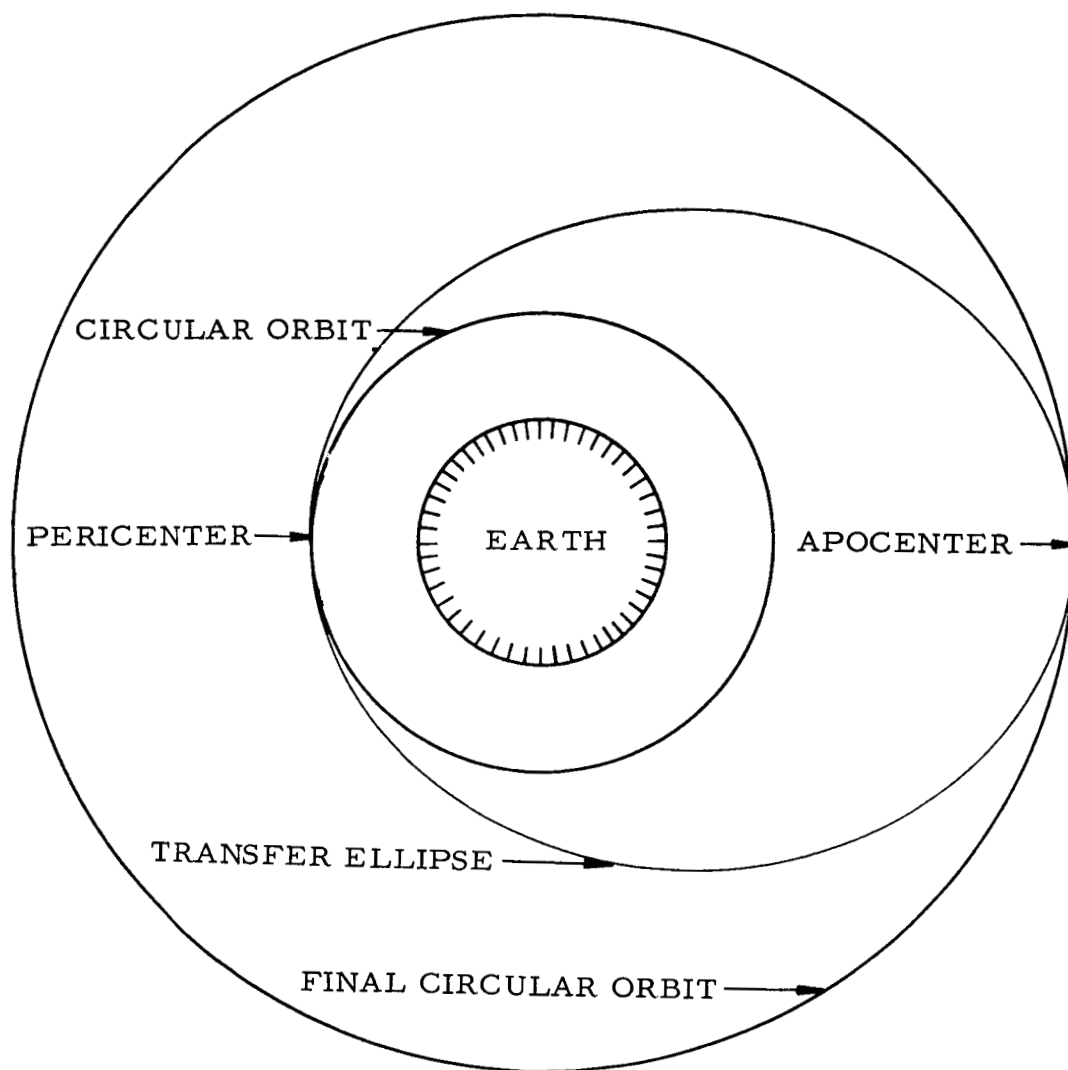


FIGURE 1. GEOMETRY OF THE ORBITAL PARAMETERS

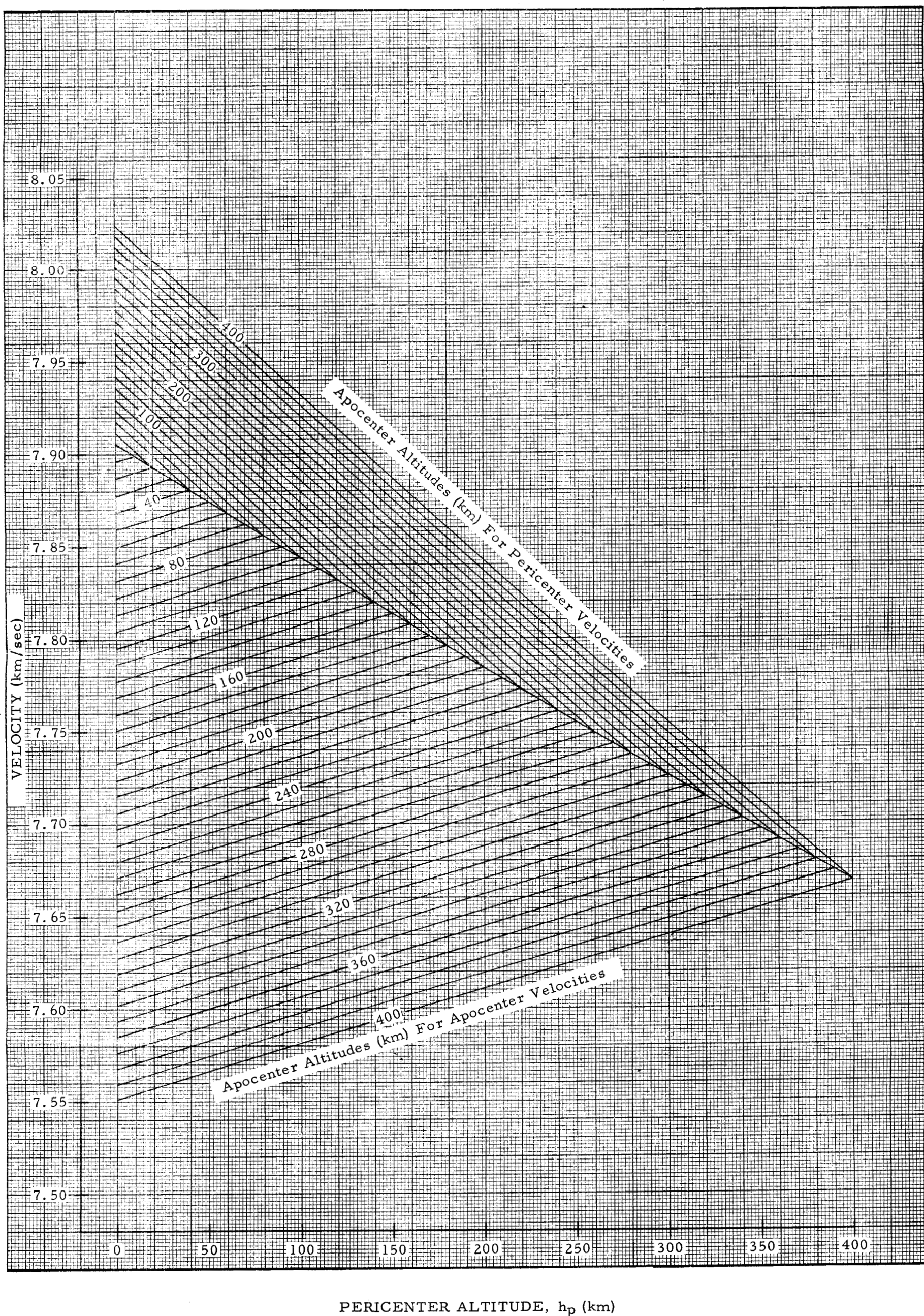
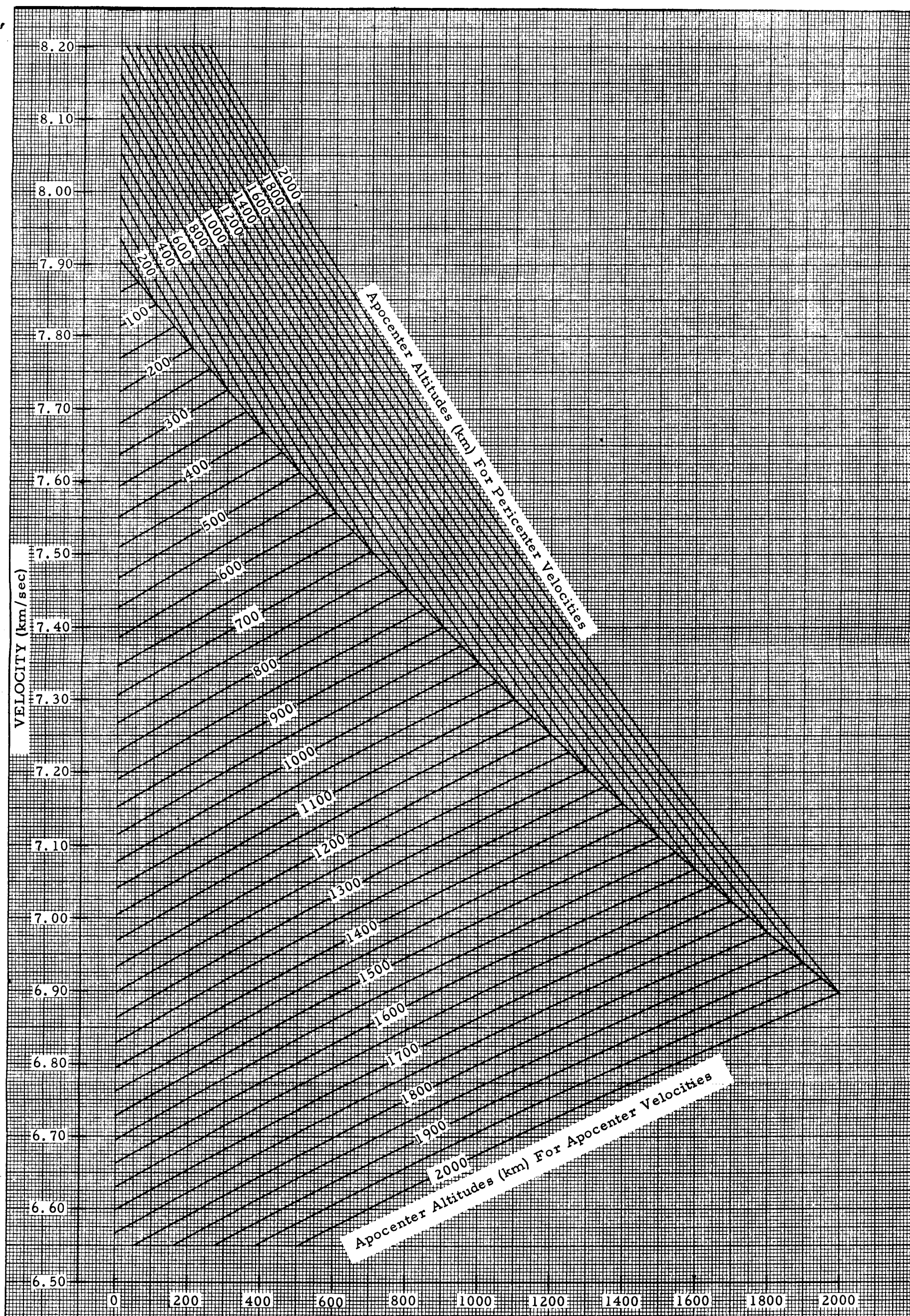


FIGURE 2a. VELOCITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE FOR PERICENTER VELOCITIES AND APOCENTER ALTITUDE FOR APOCENTER VELOCITIES AS PARAMETERS



PERICENTER ALTITUDE, h_p (km)

FIGURE 2b. VELOCITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE FOR PERICENTER VELOCITIES AND APOCENTER ALTITUDE FOR APOCENTER VELOCITIES AS PARAMETERS

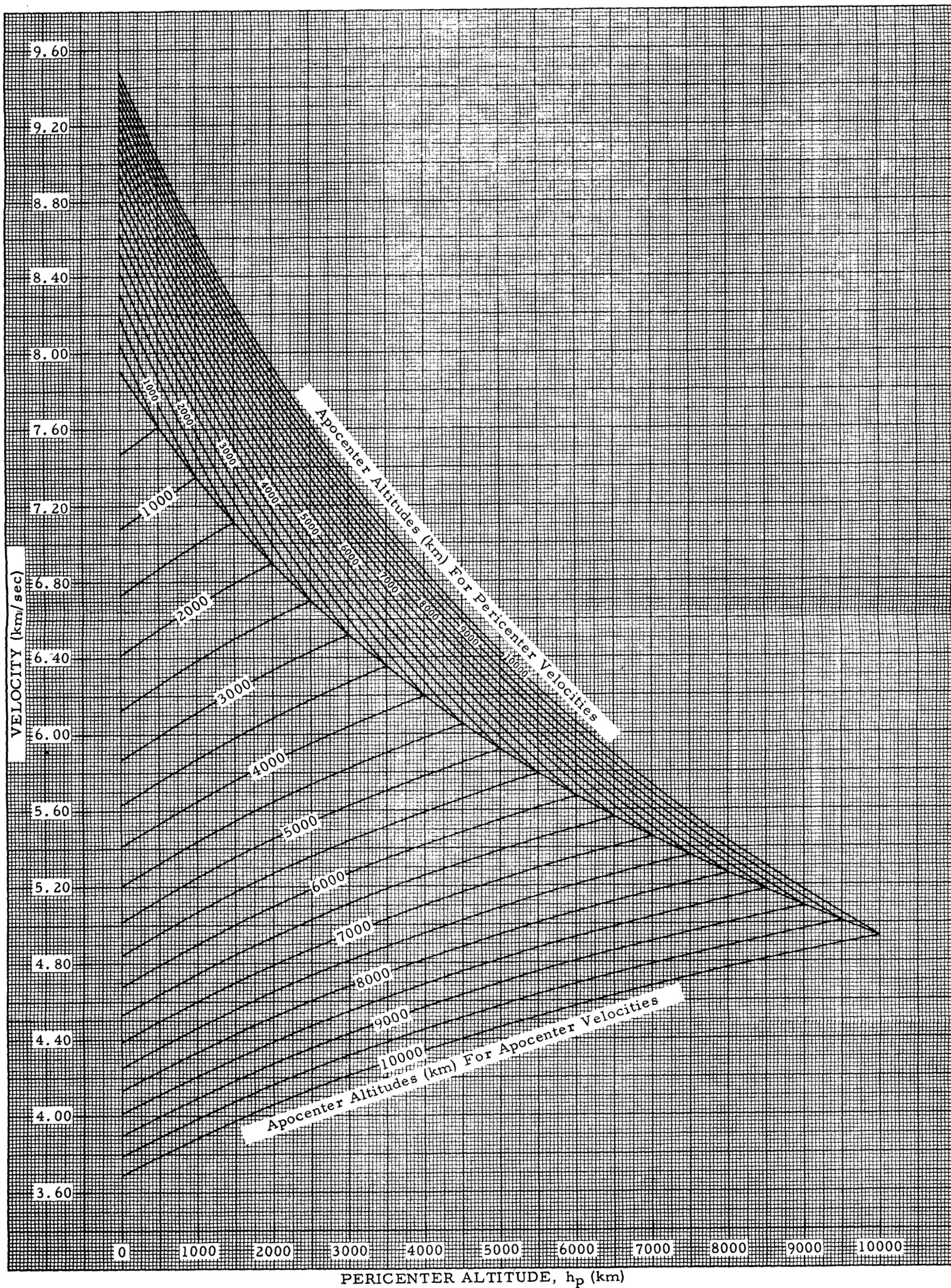


FIGURE 2c. VELOCITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE FOR PERICENTER VELOCITIES AND APOCENTER ALTITUDE FOR APOCENTER VELOCITIES AS PARAMETERS

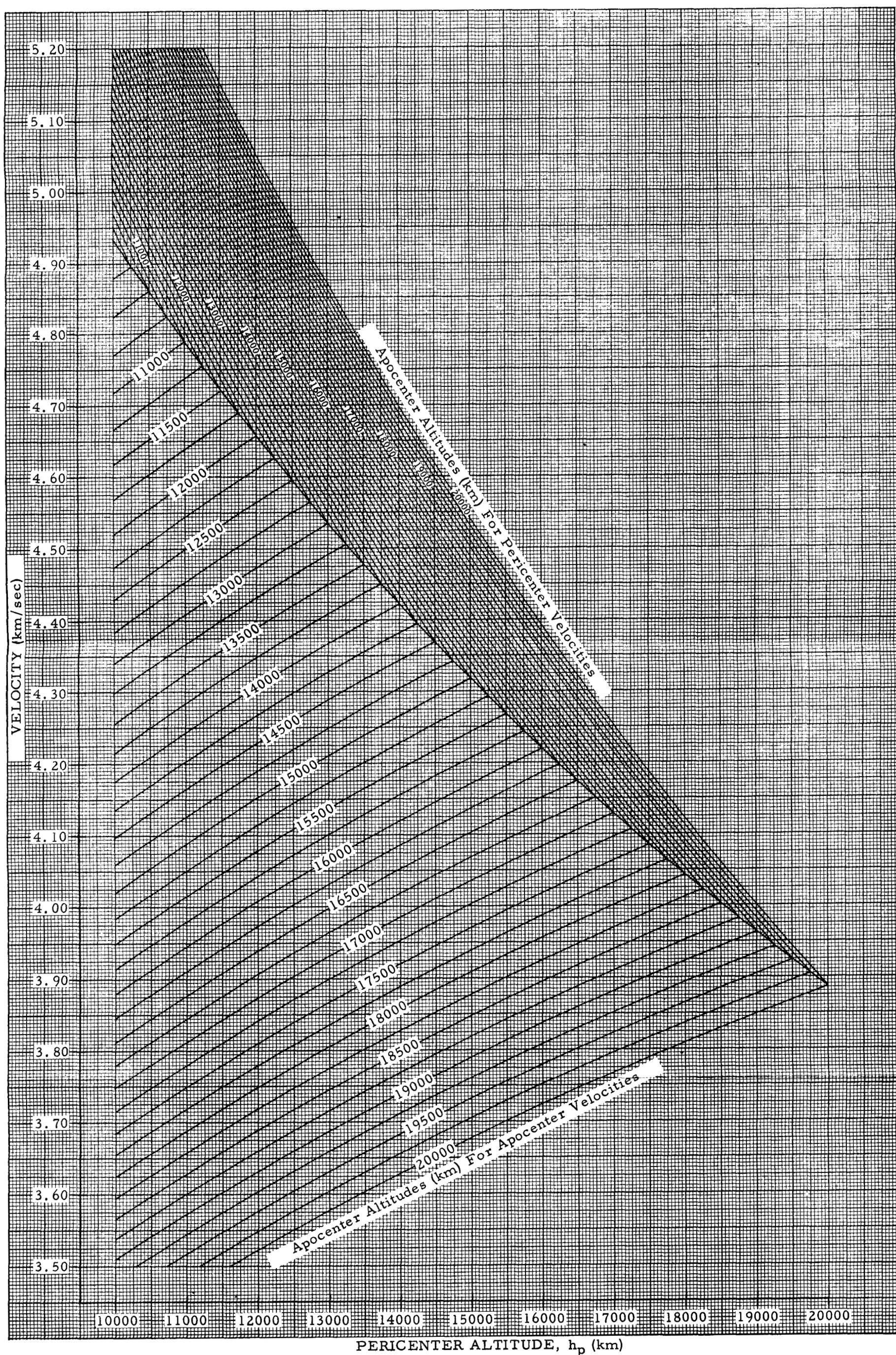


FIGURE 2d. VELOCITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE FOR PERICENTER VELOCITIES AND APOCENTER ALTITUDE FOR APOCENTER VELOCITIES AS PARAMETERS

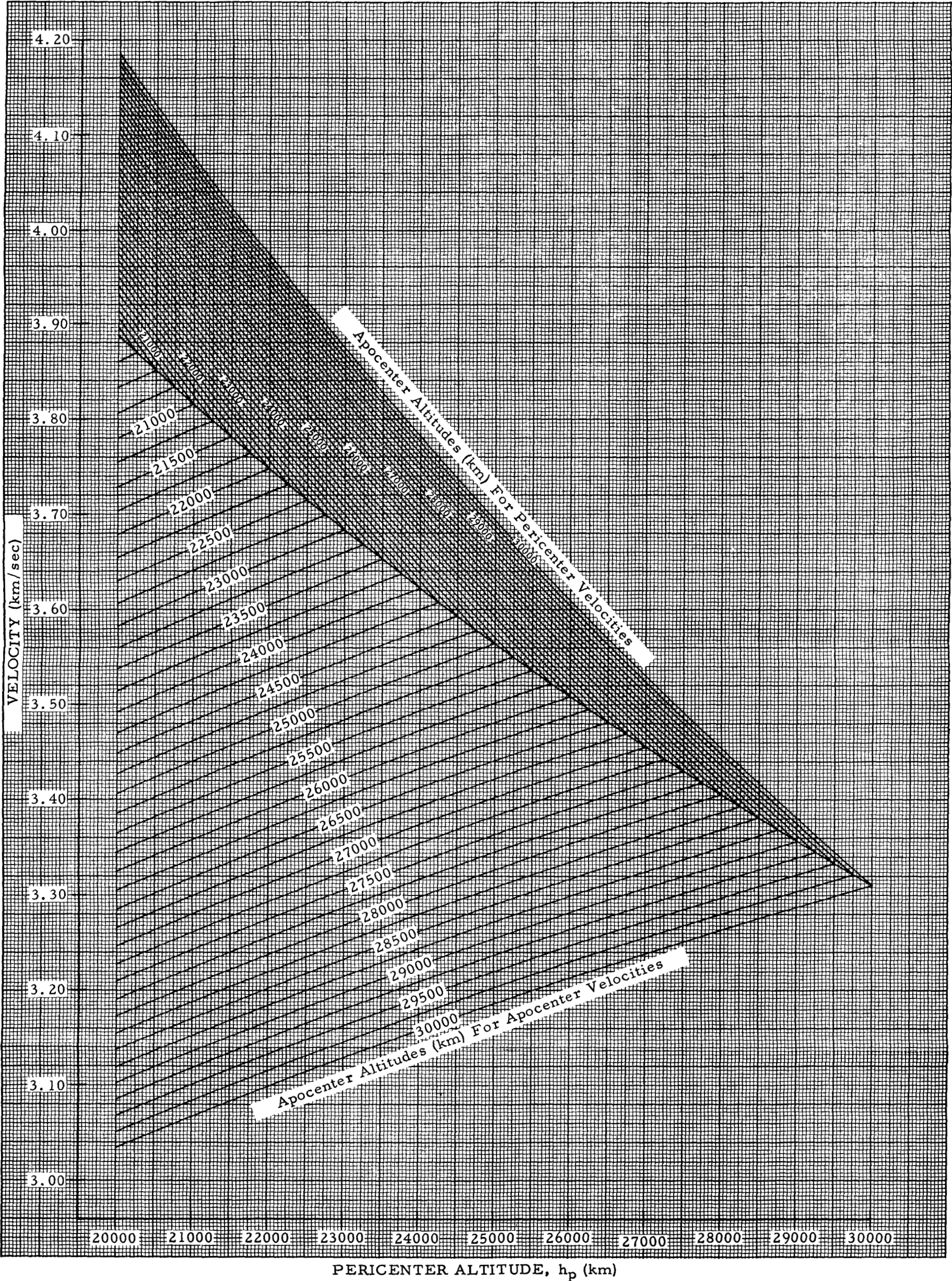


FIGURE 2e. VELOCITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE FOR PERICENTER VELOCITIES AND APOCENTER ALTITUDE FOR APOCENTER VELOCITIES AS PARAMETERS

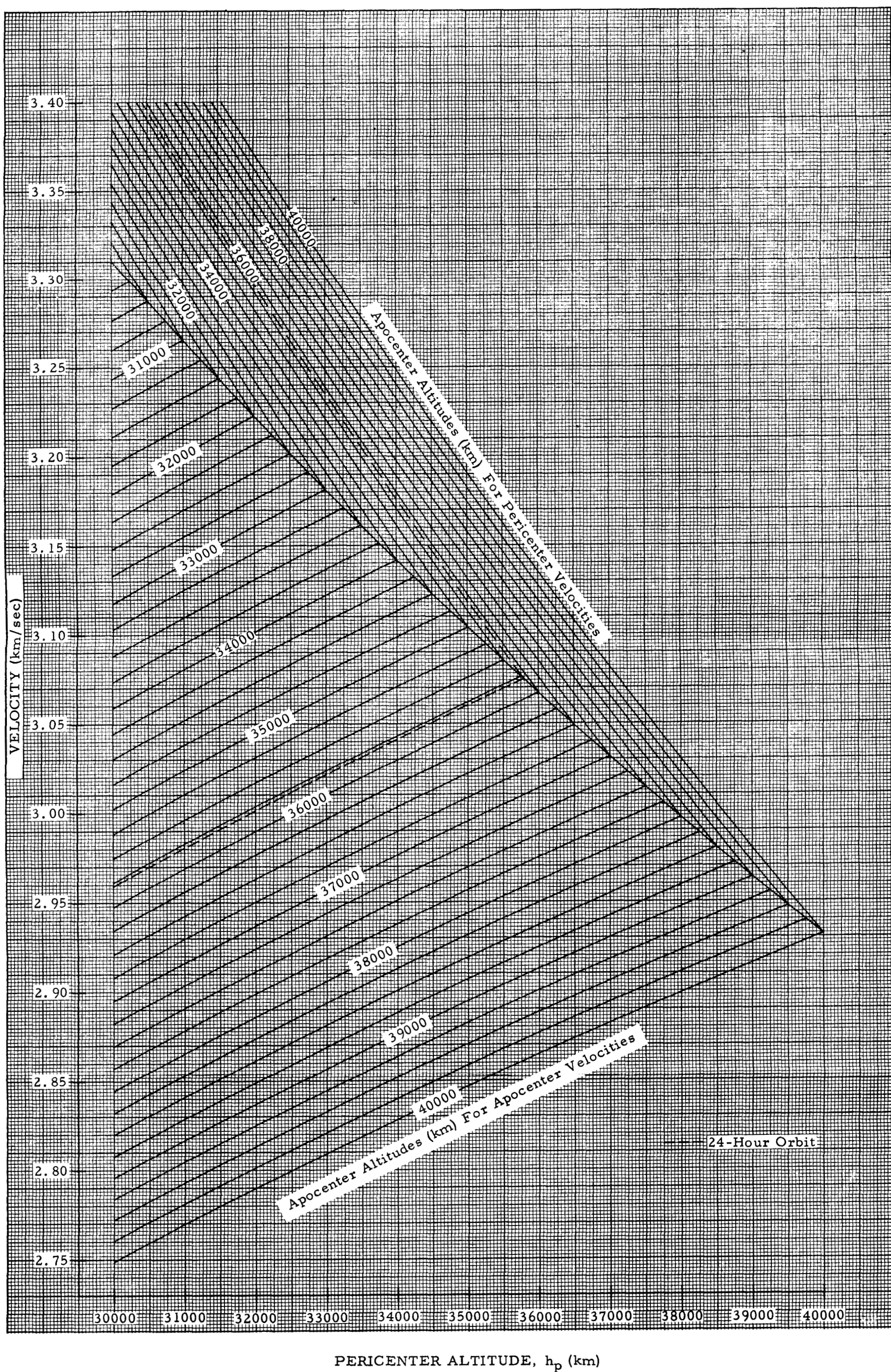


FIGURE 2f. VELOCITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE FOR PERICENTER VELOCITIES AND APOCENTER ALTITUDE FOR APOCENTER VELOCITIES AS PARAMETERS

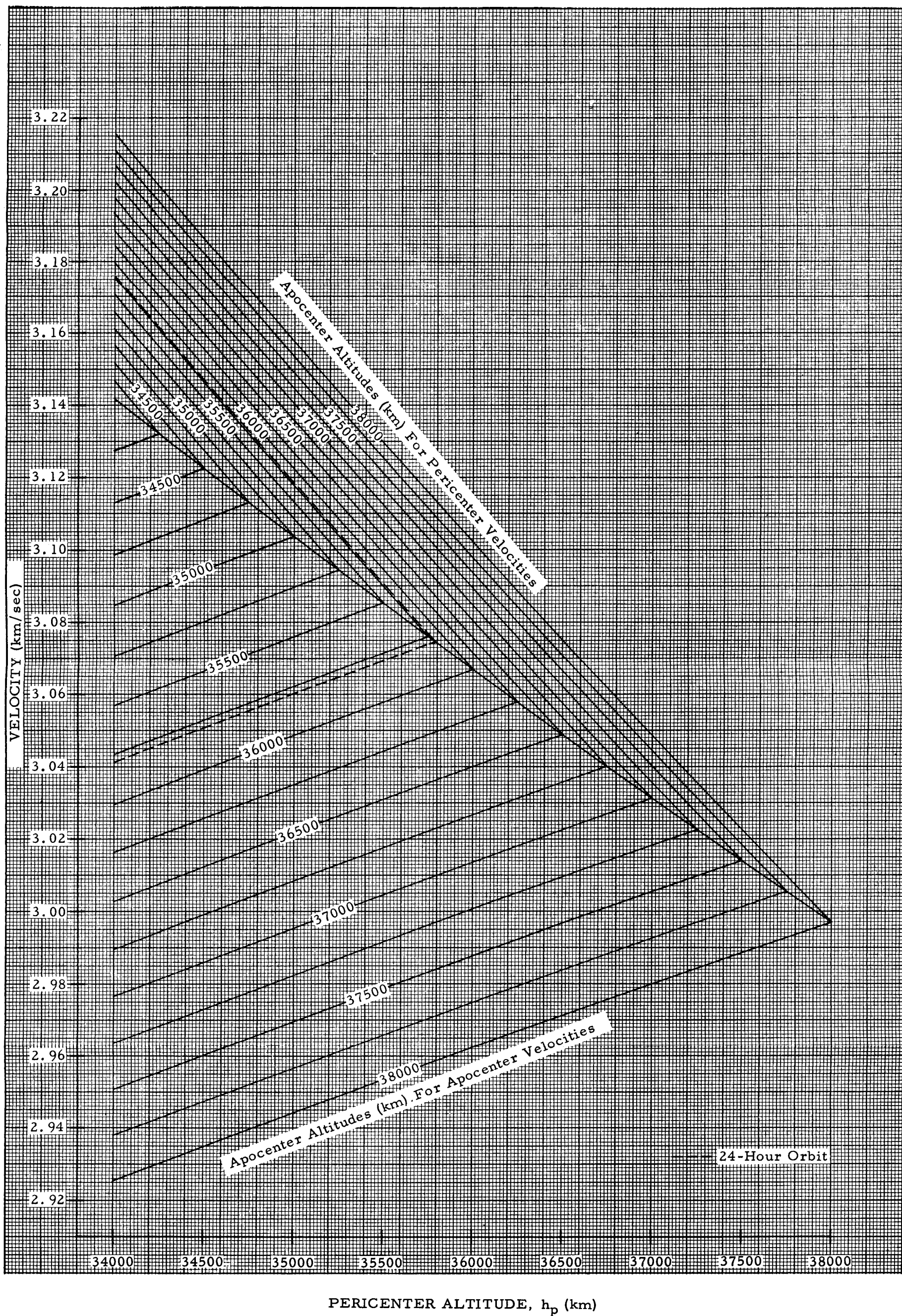


FIGURE 2g. VELOCITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE FOR PERICENTER VELOCITIES AND APOCENTER ALTITUDE FOR APOCENTER VELOCITIES AS PARAMETERS

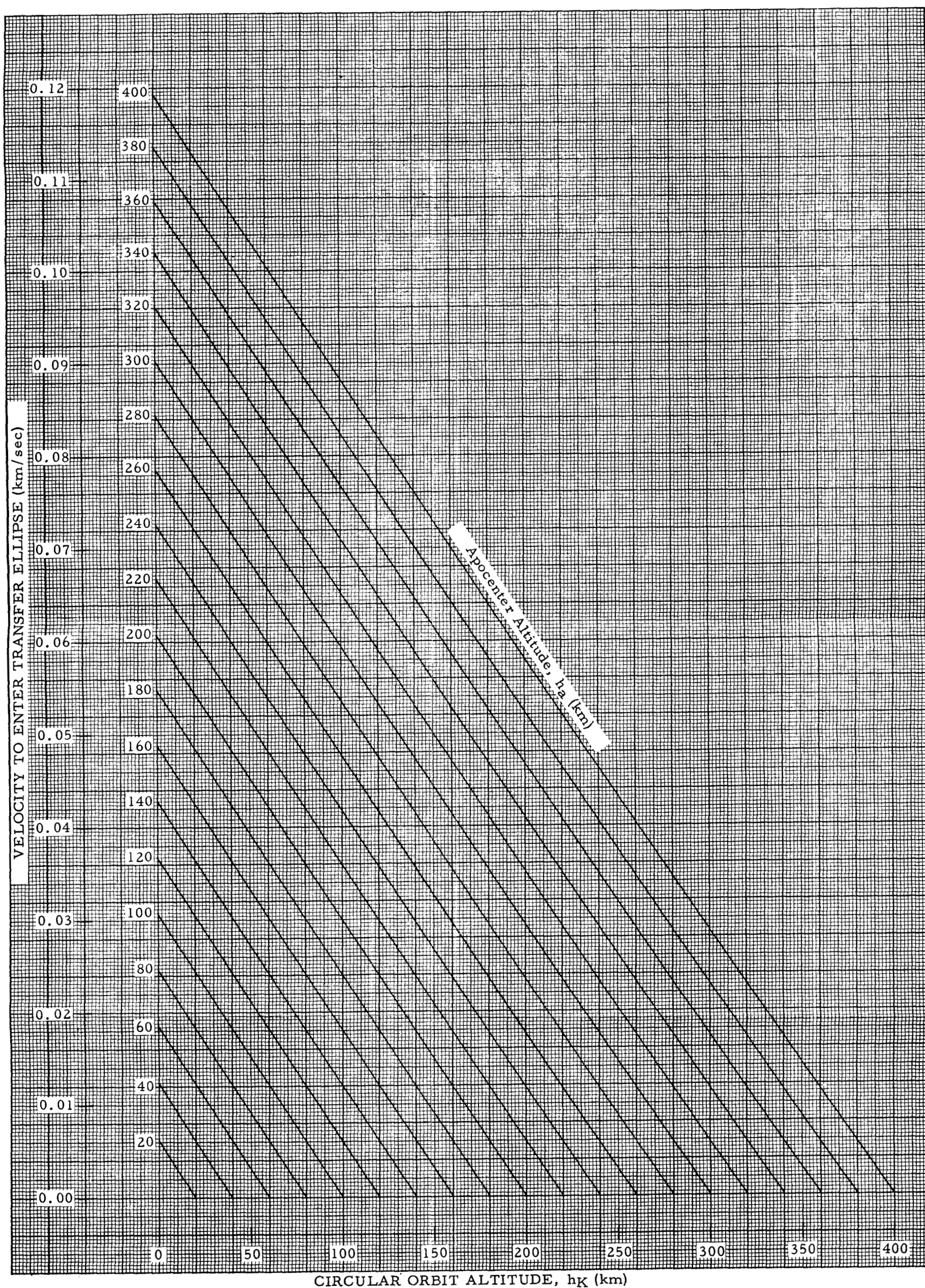


FIGURE 3a. VELOCITY REQUIRED FOR TRANSFER FROM A CIRCULAR TO AN ECCENTRIC ORBIT VERSUS CIRCULAR ORBIT ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

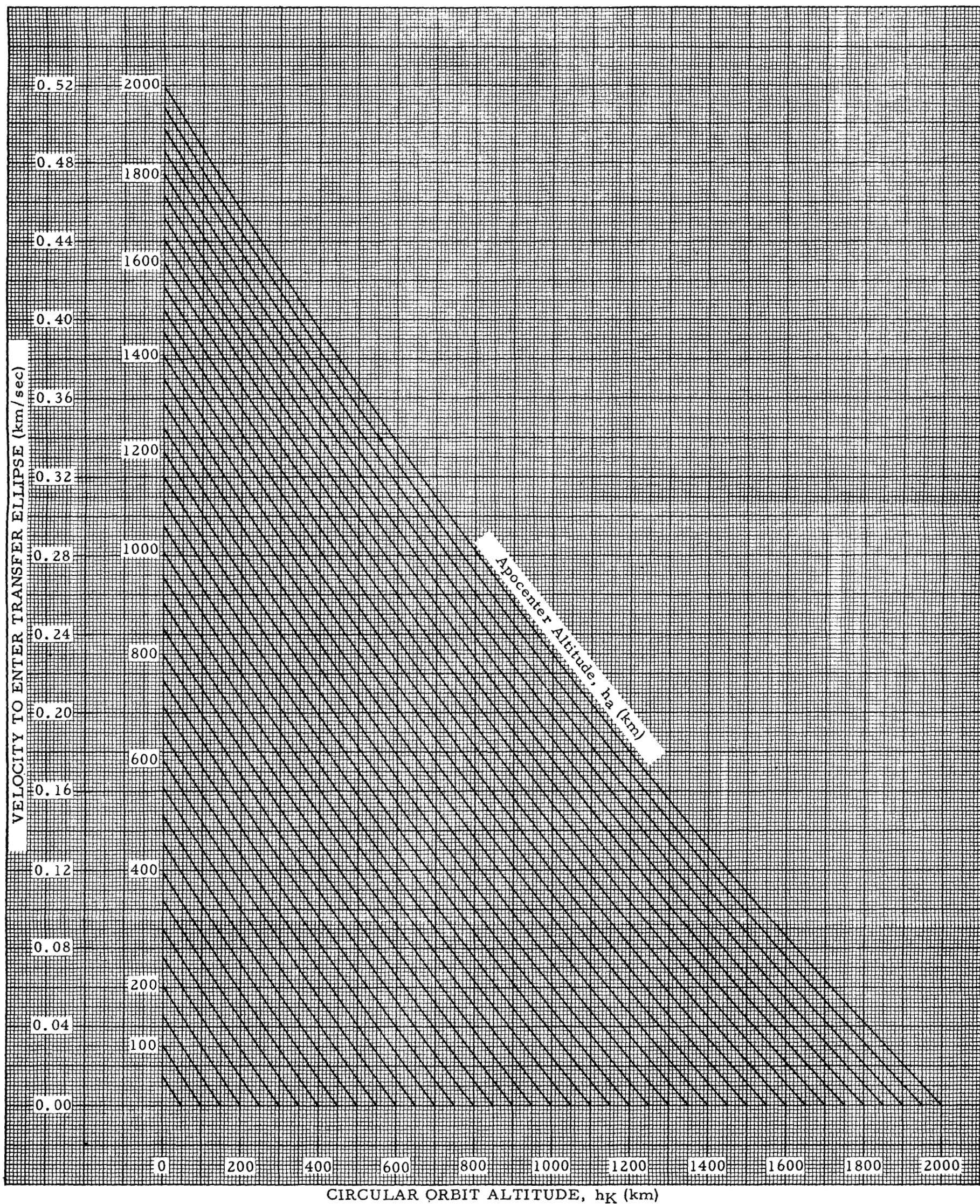


FIGURE 3b. VELOCITY REQUIRED FOR TRANSFER FROM A CIRCULAR TO AN ECCENTRIC ORBIT
VERSUS CIRCULAR ORBIT ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

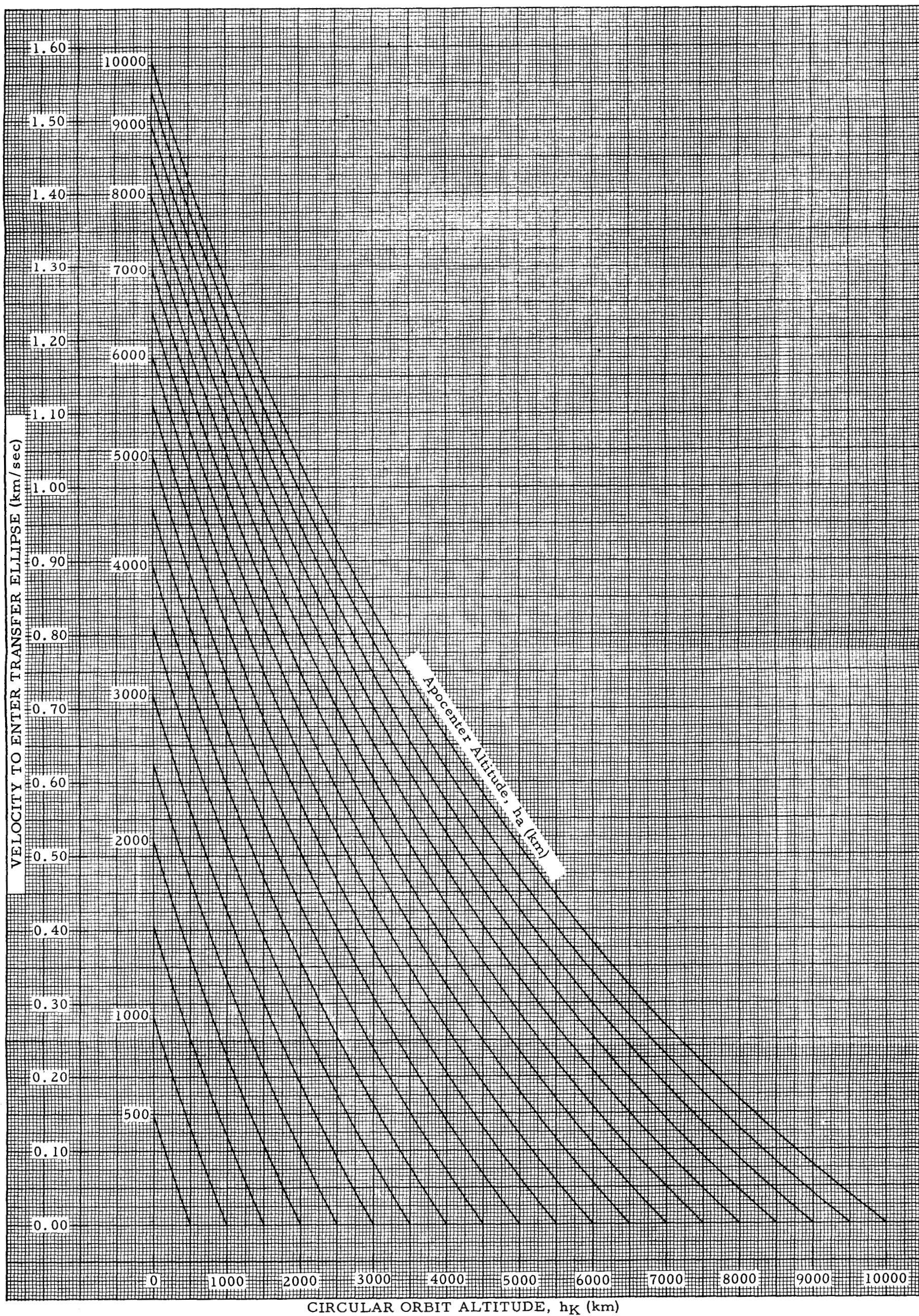


FIGURE 3c. VELOCITY REQUIRED FOR TRANSFER FROM A CIRCULAR TO AN ECCENTRIC ORBIT VERSUS CIRCULAR ORBIT ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

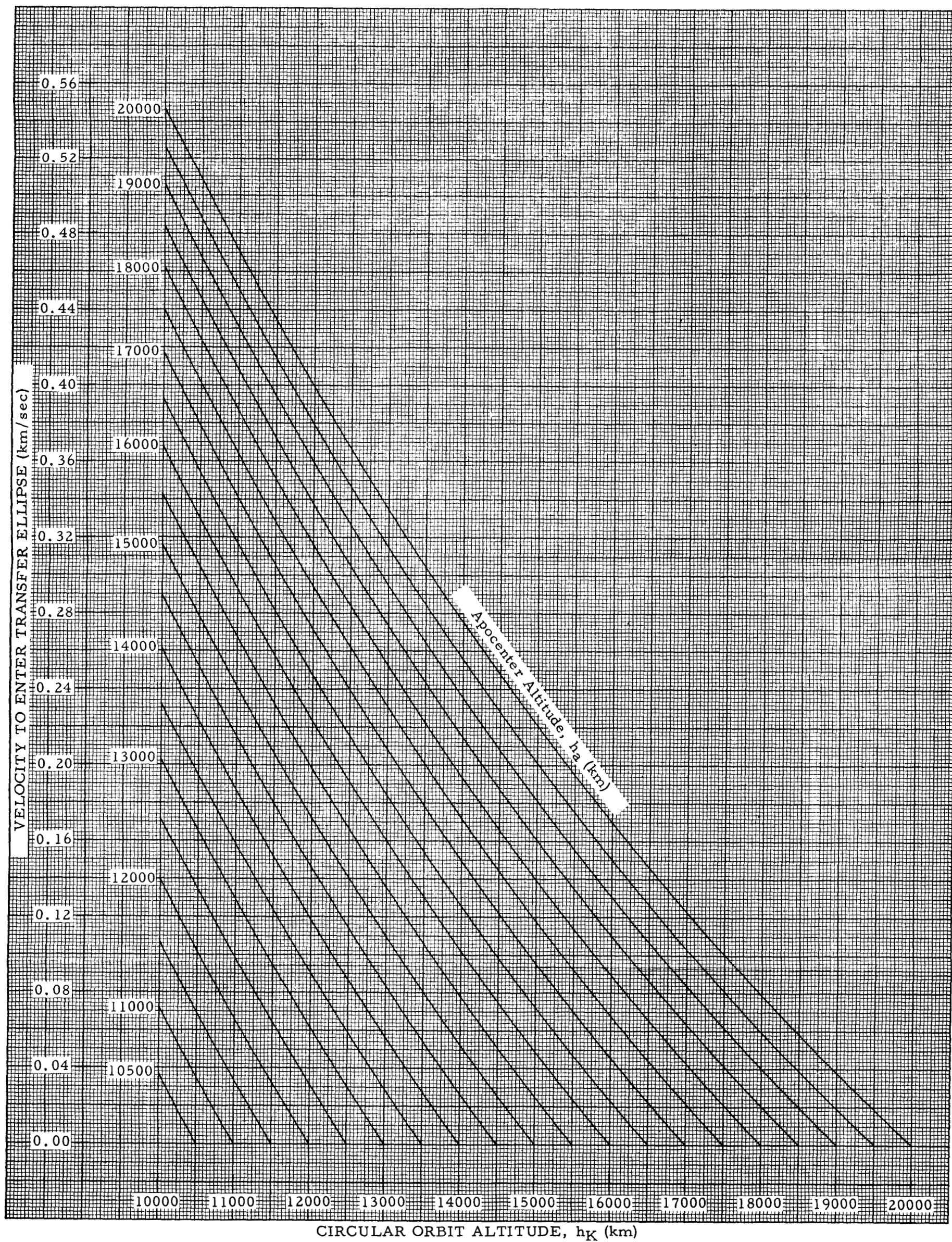


FIGURE 3d. VELOCITY REQUIRED FOR TRANSFER FROM A CIRCULAR TO AN ECCENTRIC ORBIT VERSUS CIRCULAR ORBIT ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

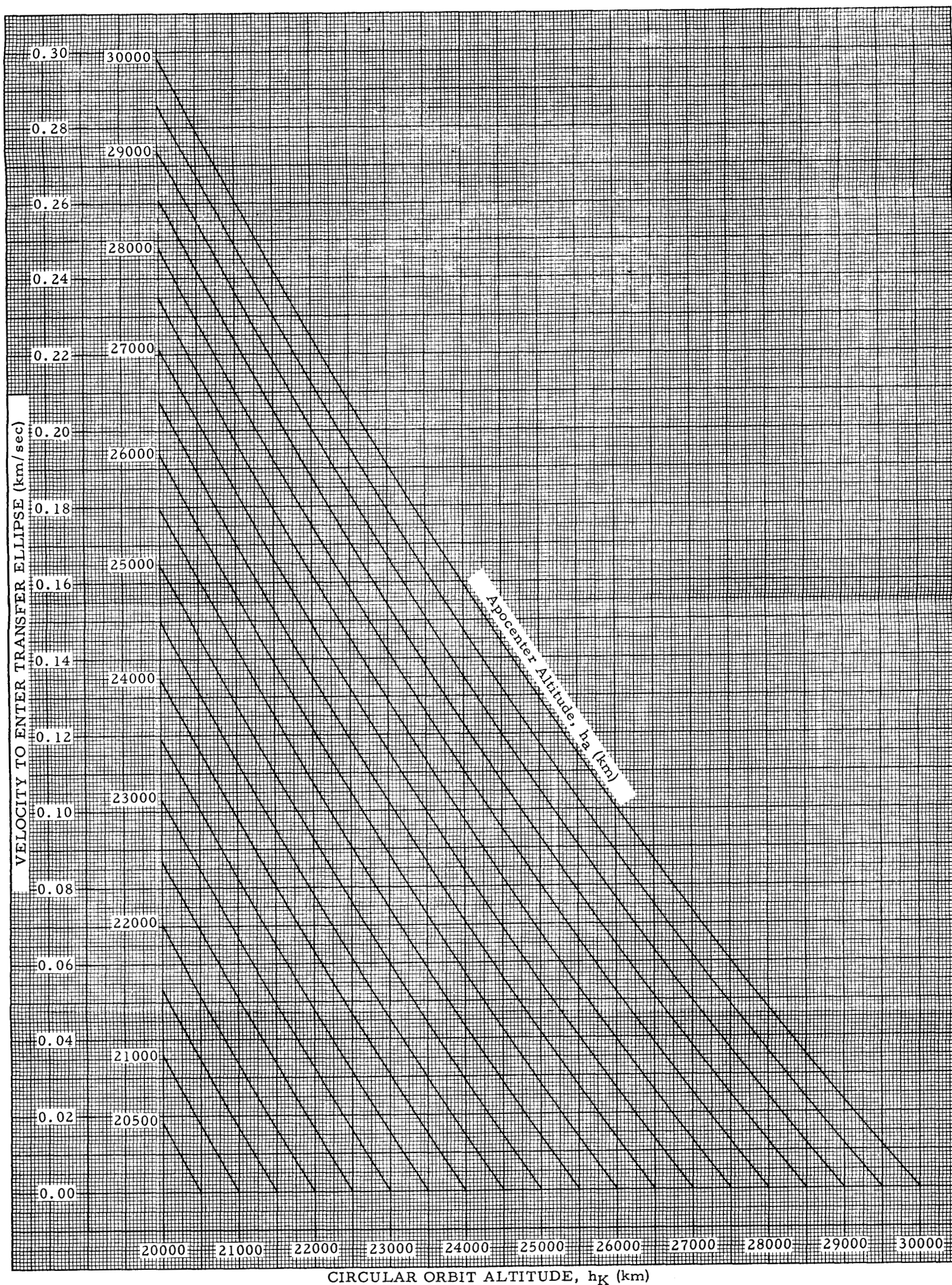


FIGURE 3e. VELOCITY REQUIRED FOR TRANSFER FROM A CIRCULAR TO AN ECCENTRIC ORBIT VERSUS CIRCULAR ORBIT ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

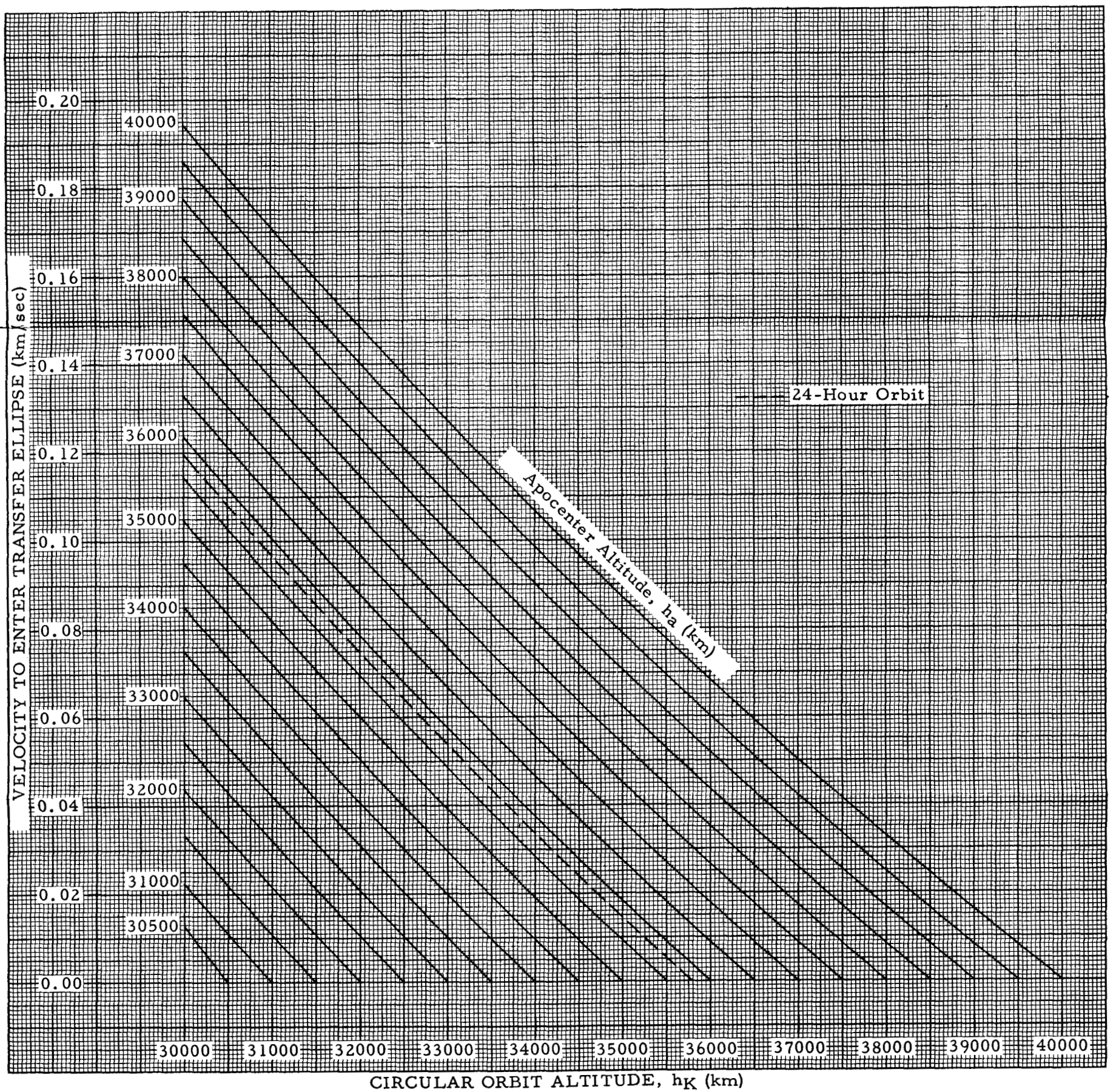


FIGURE 3f. VELOCITY REQUIRED FOR TRANSFER FROM A CIRCULAR TO AN ECCENTRIC ORBIT VERSUS CIRCULAR ORBIT ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

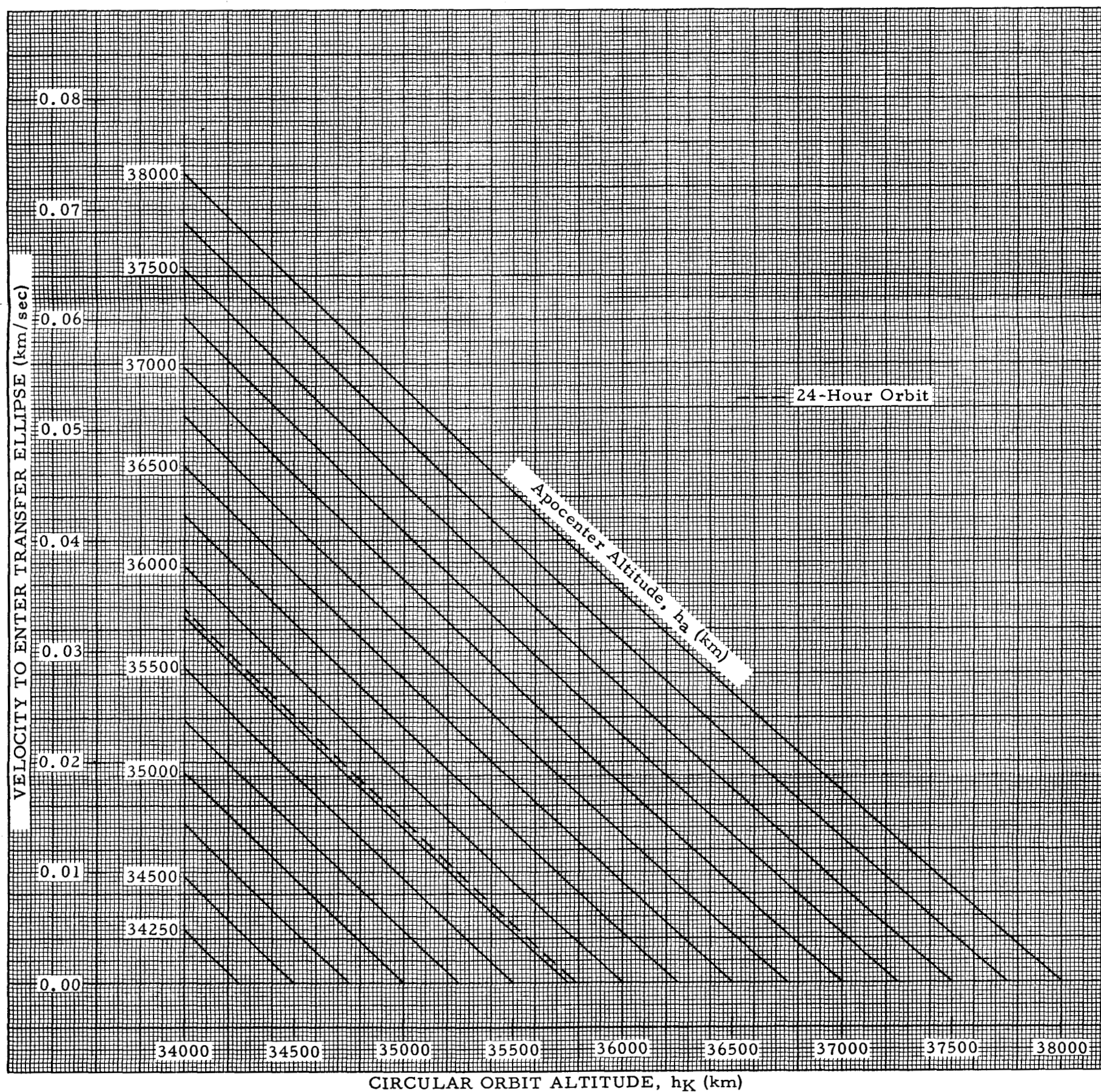


FIGURE 3g. VELOCITY REQUIRED FOR TRANSFER FROM A CIRCULAR TO AN ECCENTRIC ORBIT VERSUS CIRCULAR ORBIT ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

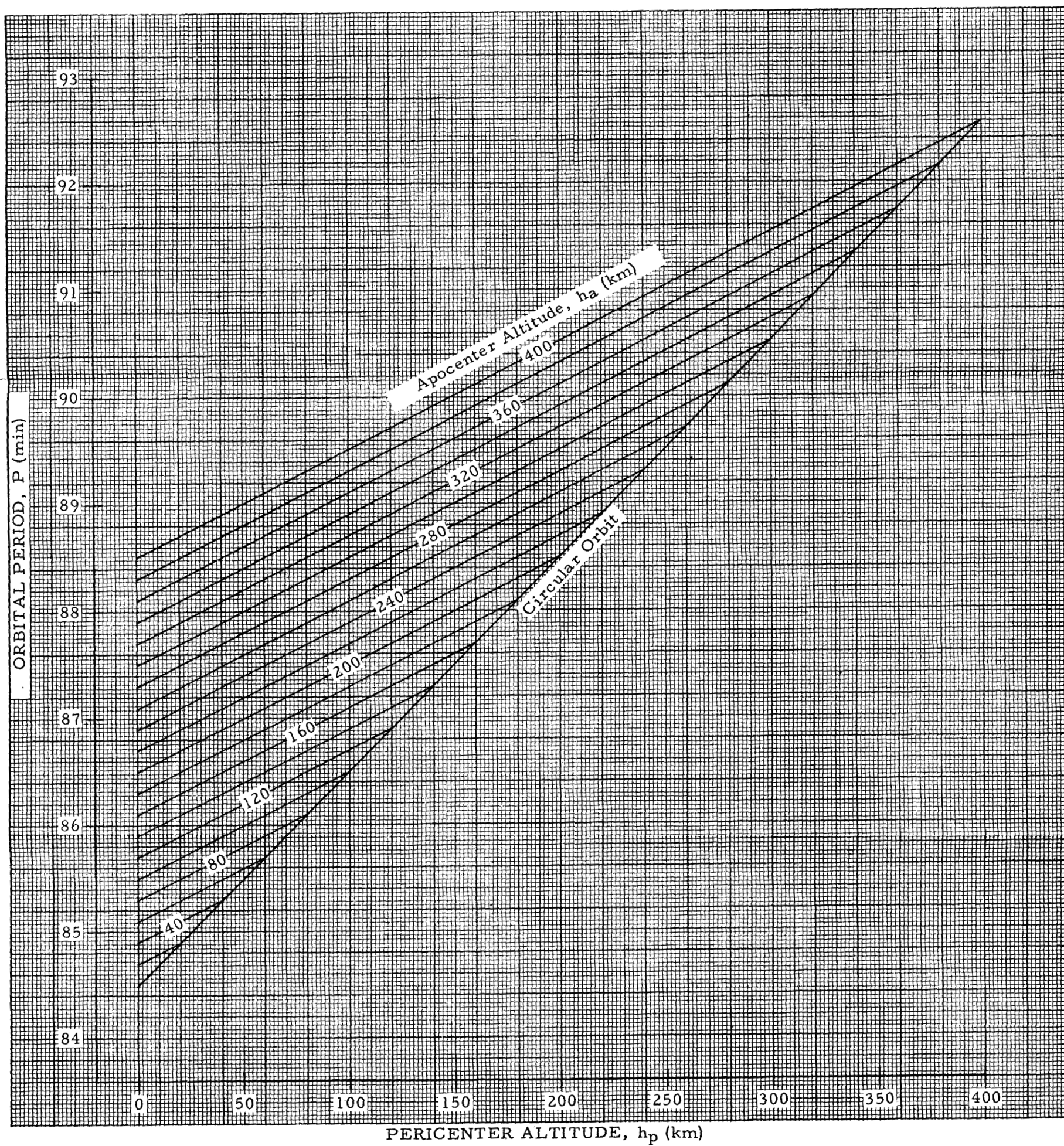


FIGURE 4a. ORBITAL PERIOD VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

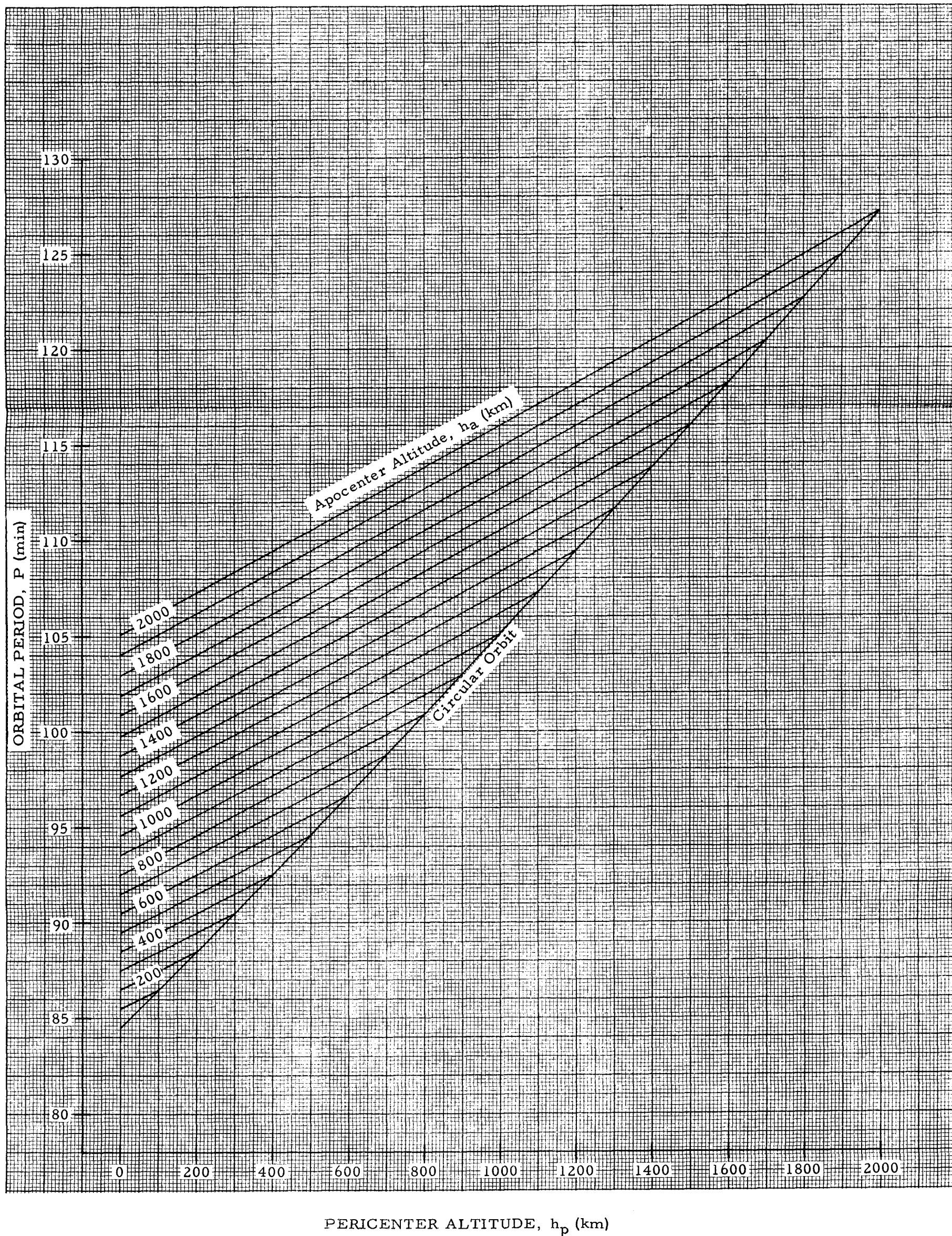


FIGURE 4b. ORBITAL PERIOD VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

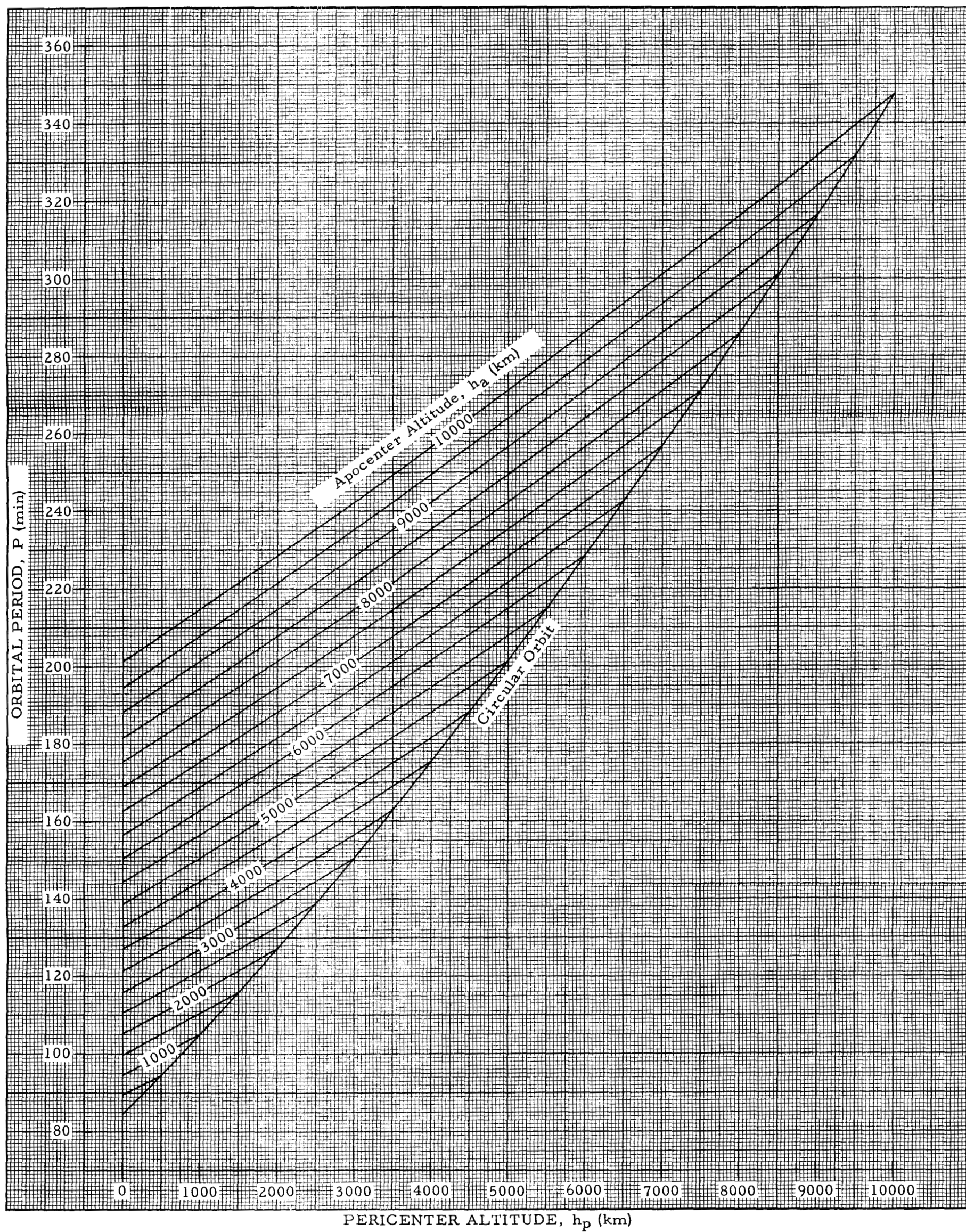


FIGURE 4c. ORBITAL PERIOD VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

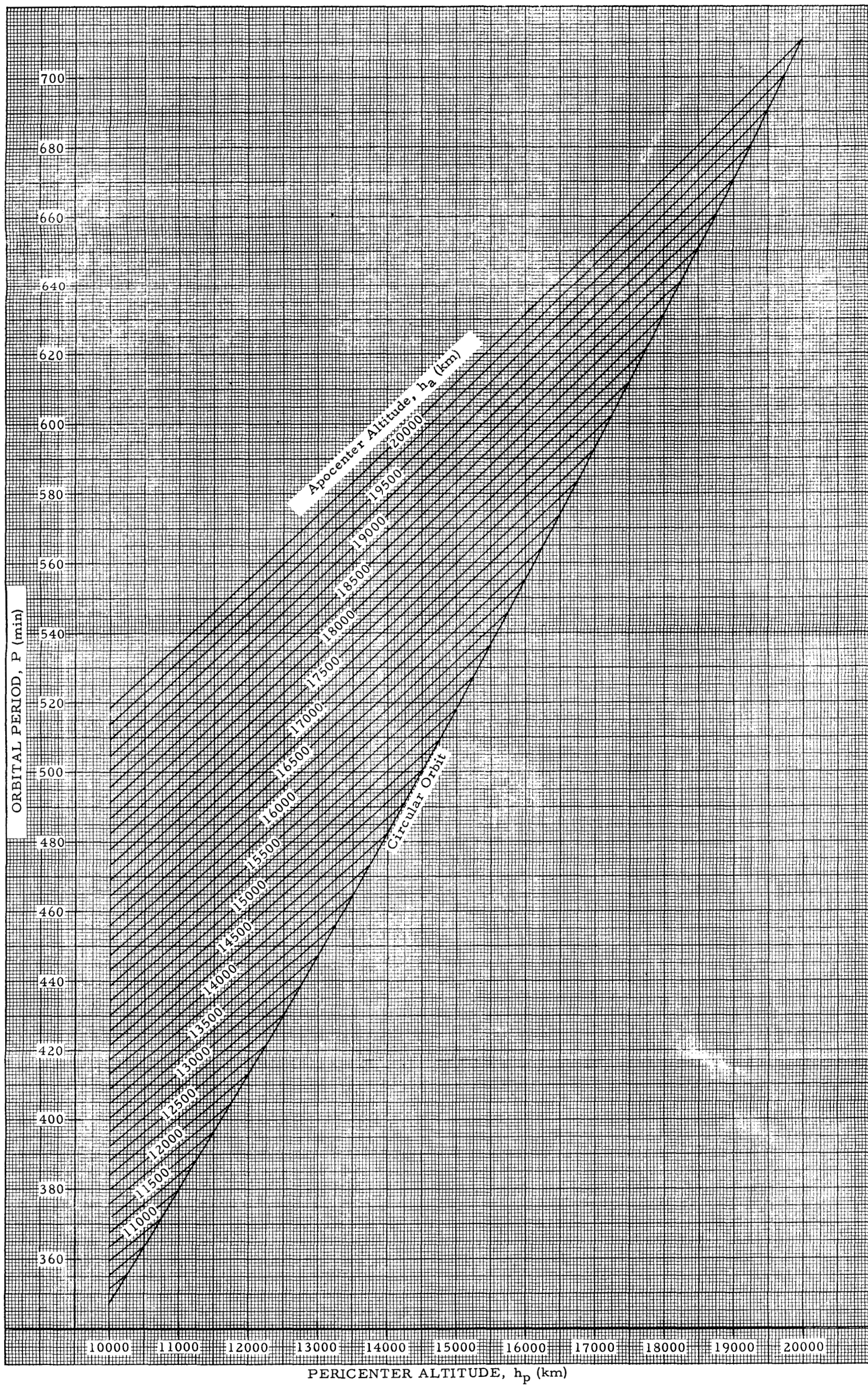


FIGURE 4d. ORBITAL PERIOD VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

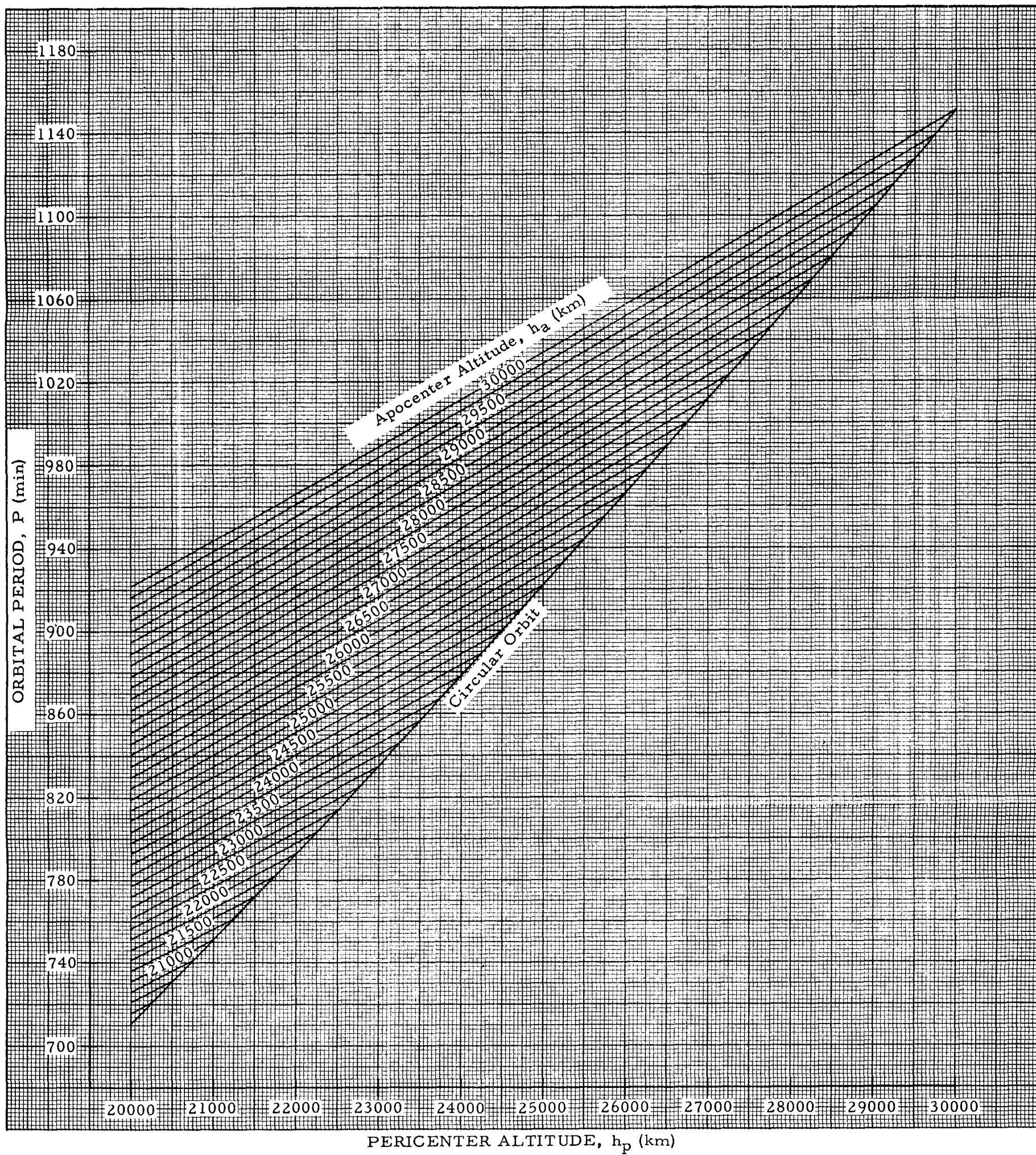


FIGURE 4e. ORBITAL PERIOD VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

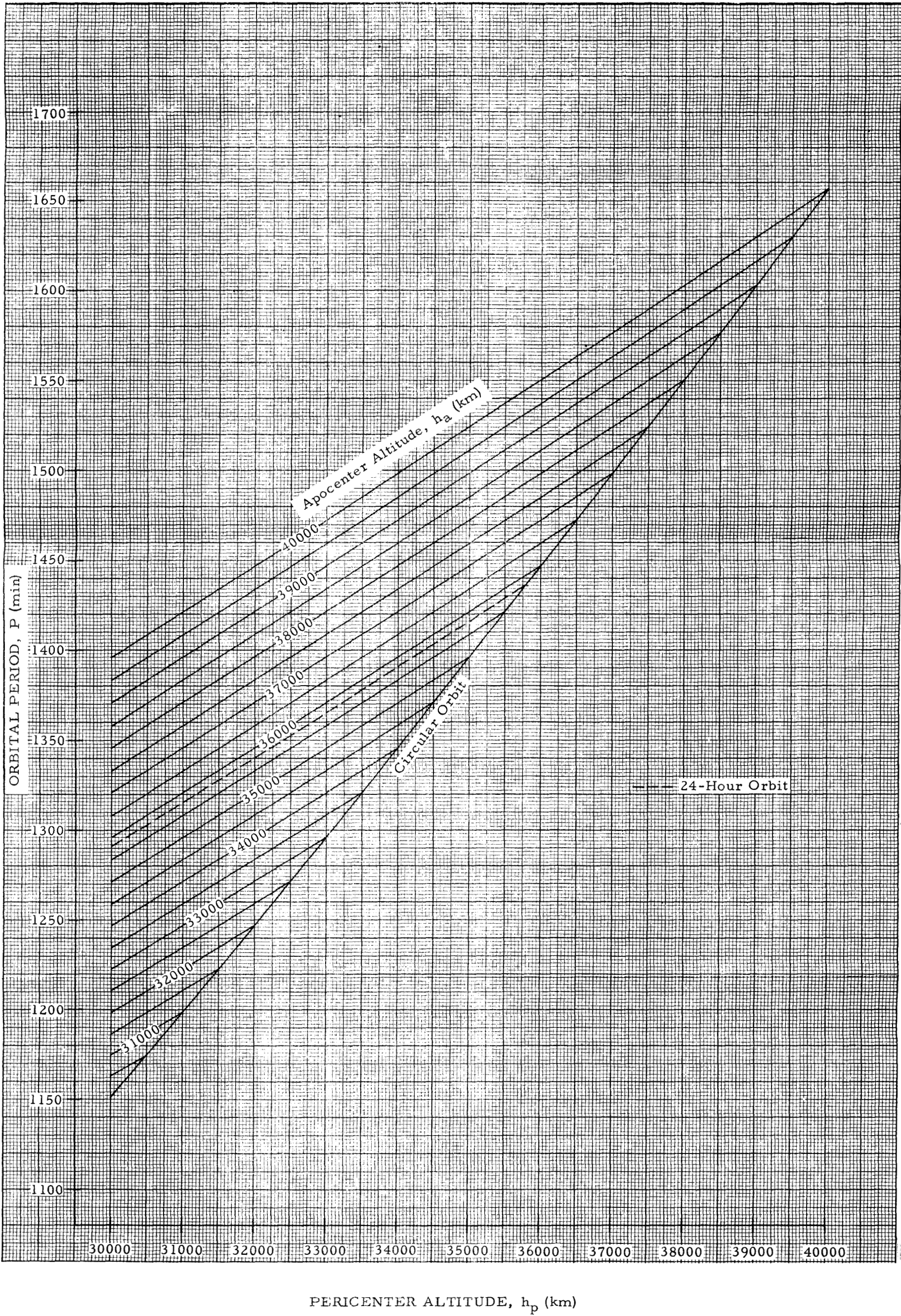


FIGURE 4f. ORBITAL PERIOD VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

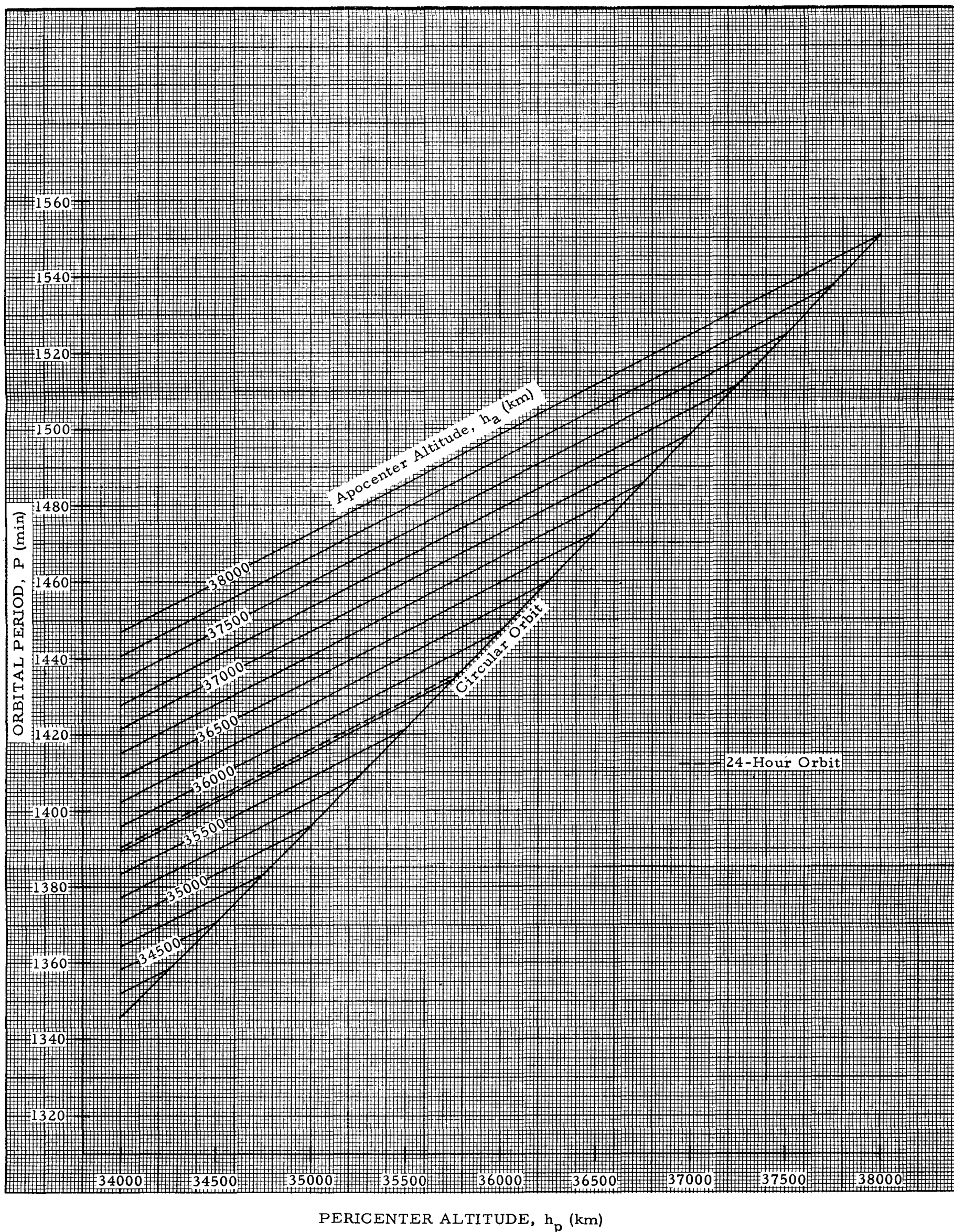


FIGURE 4g. ORBITAL PERIOD VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

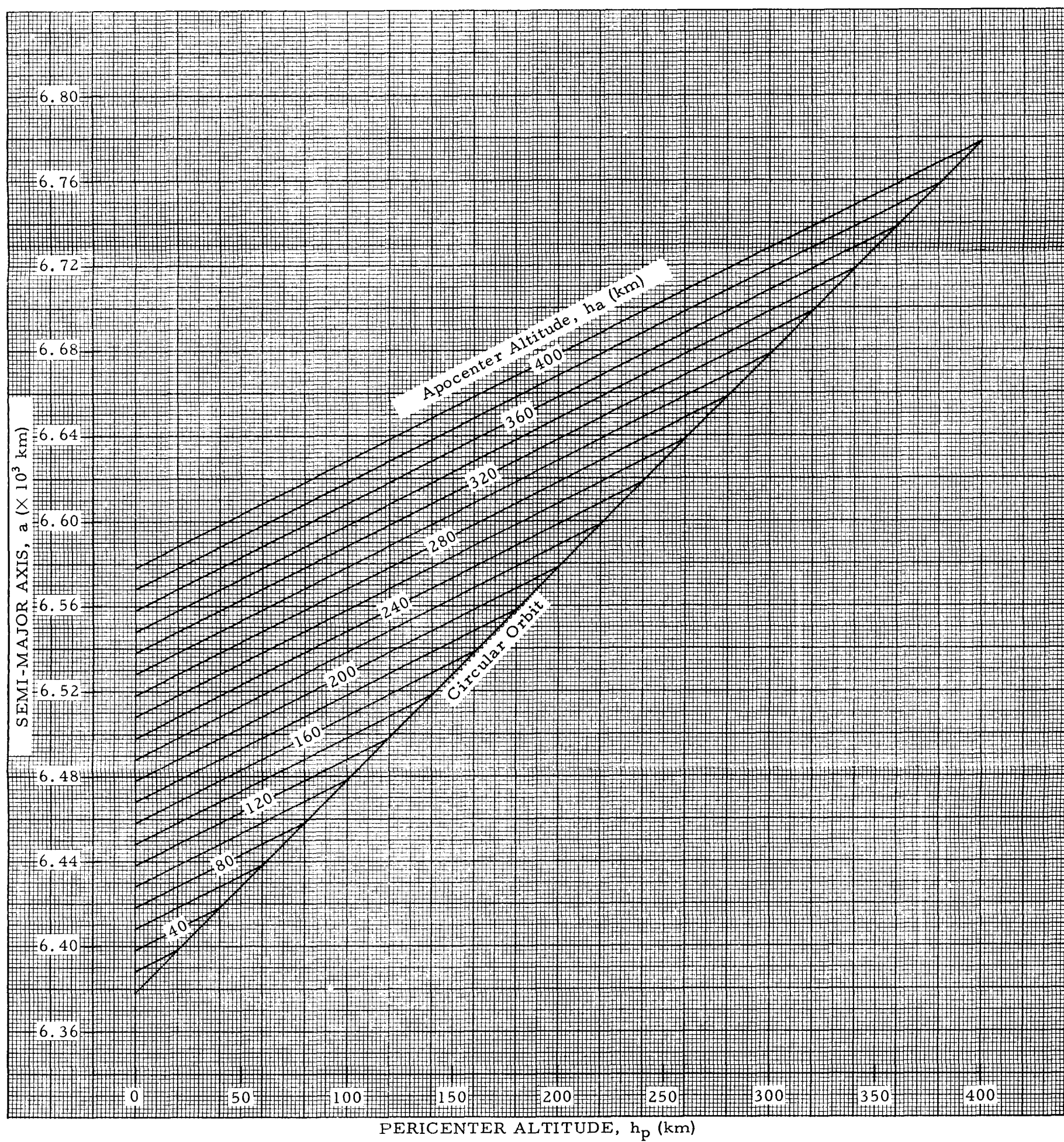


FIGURE 5a. SEMI-MAJOR AXIS VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

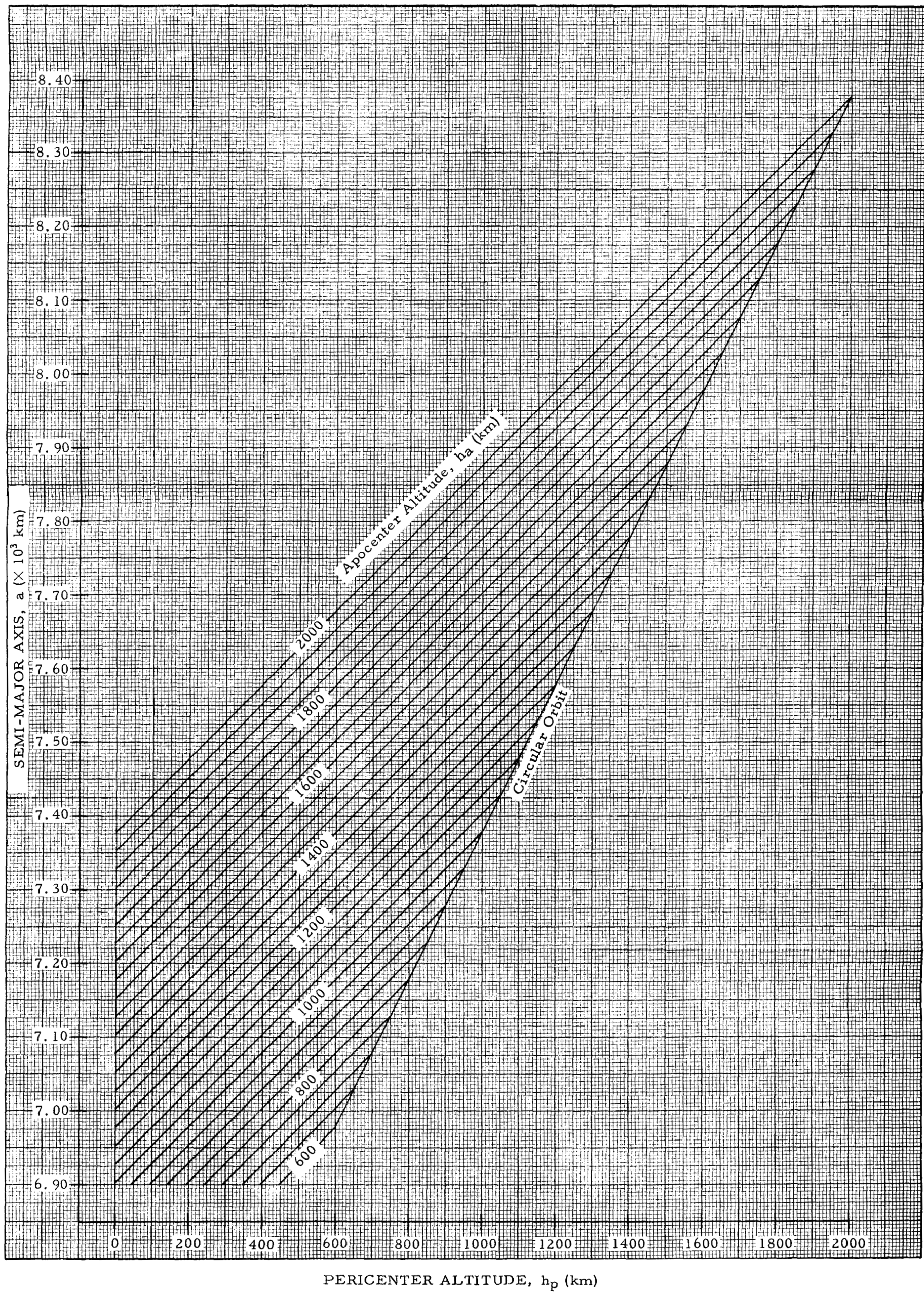


FIGURE 5b. SEMI-MAJOR AXIS VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

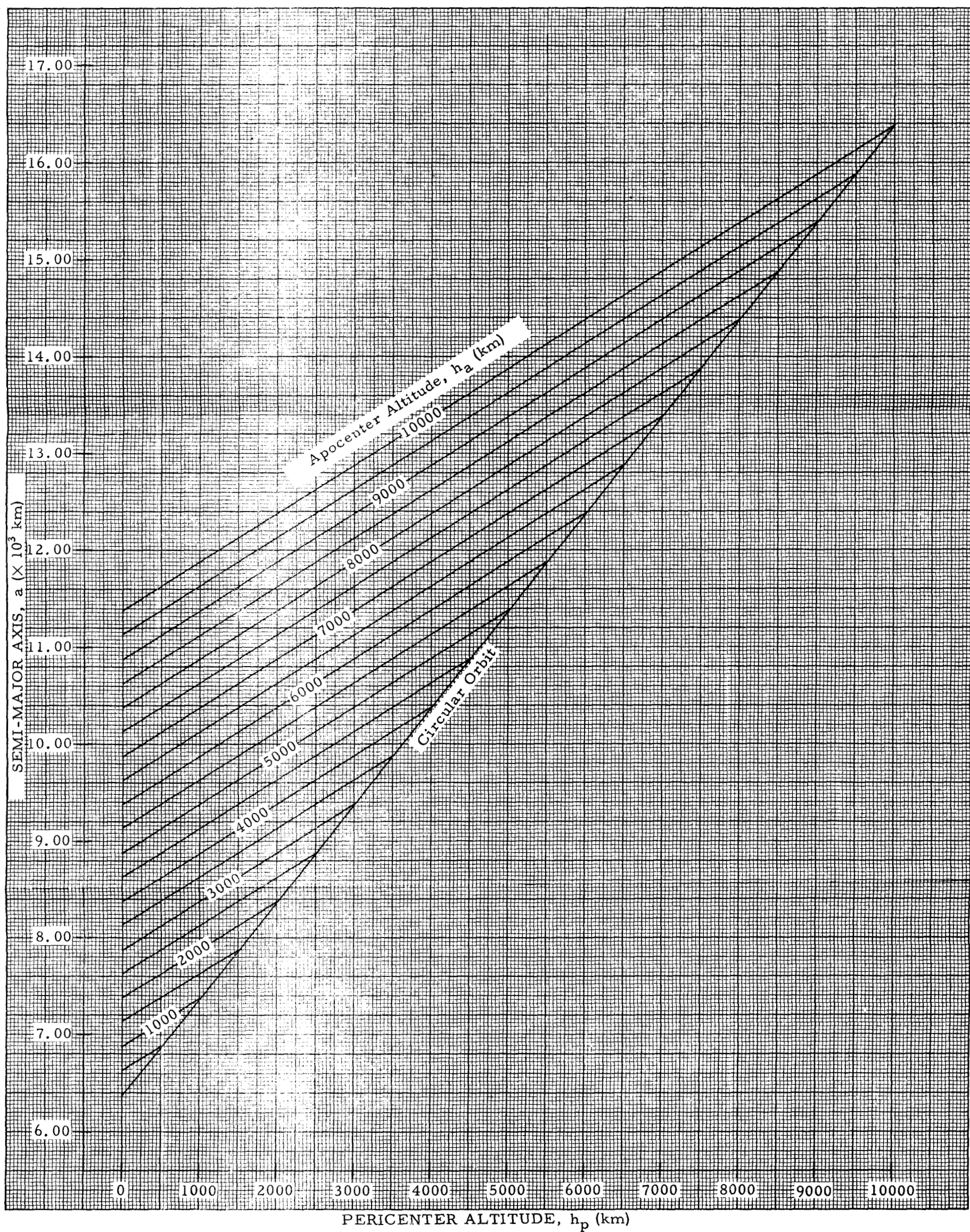


FIGURE 5c. SEMI-MAJOR AXIS VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

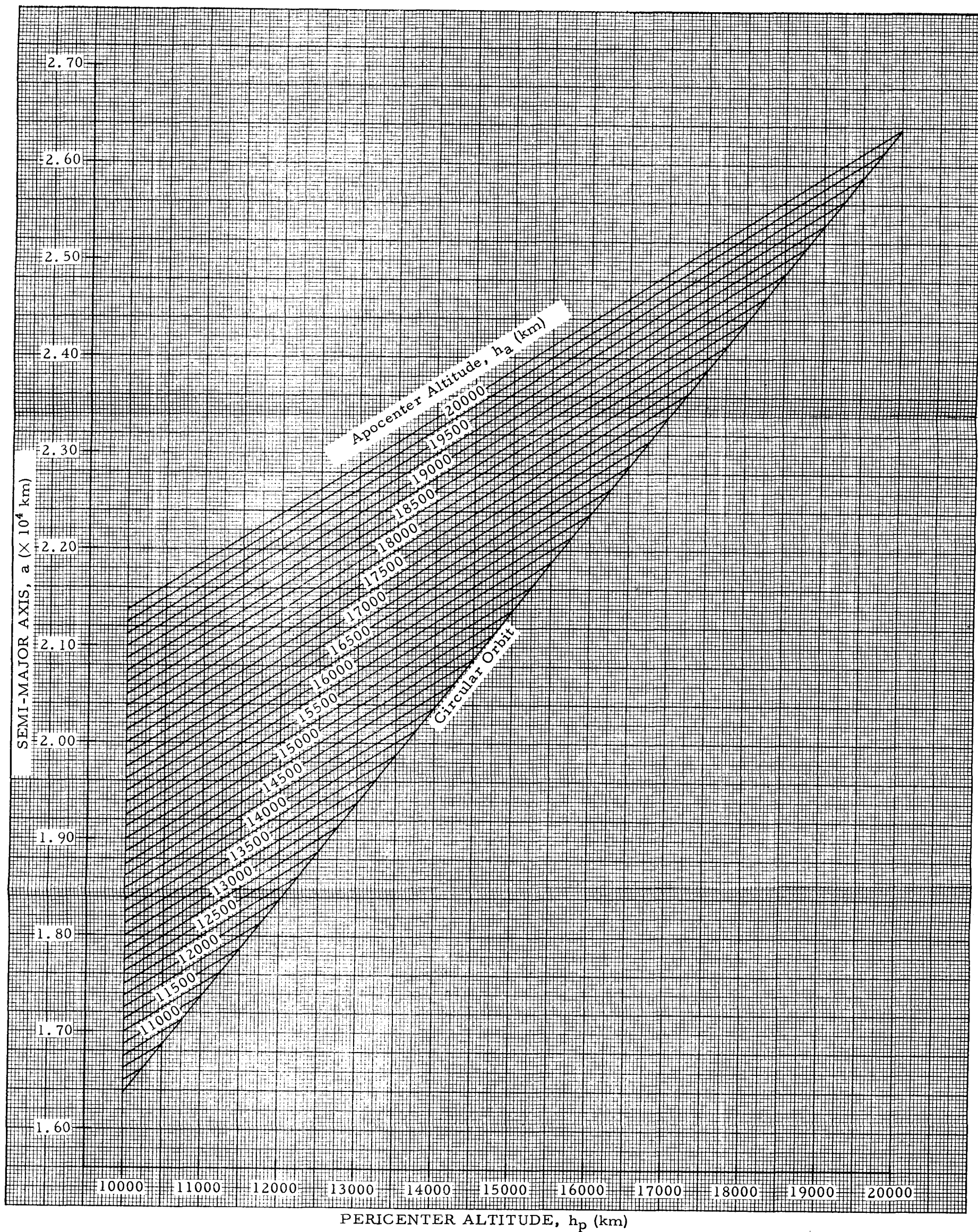


FIGURE 5d. SEMI-MAJOR AXIS VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

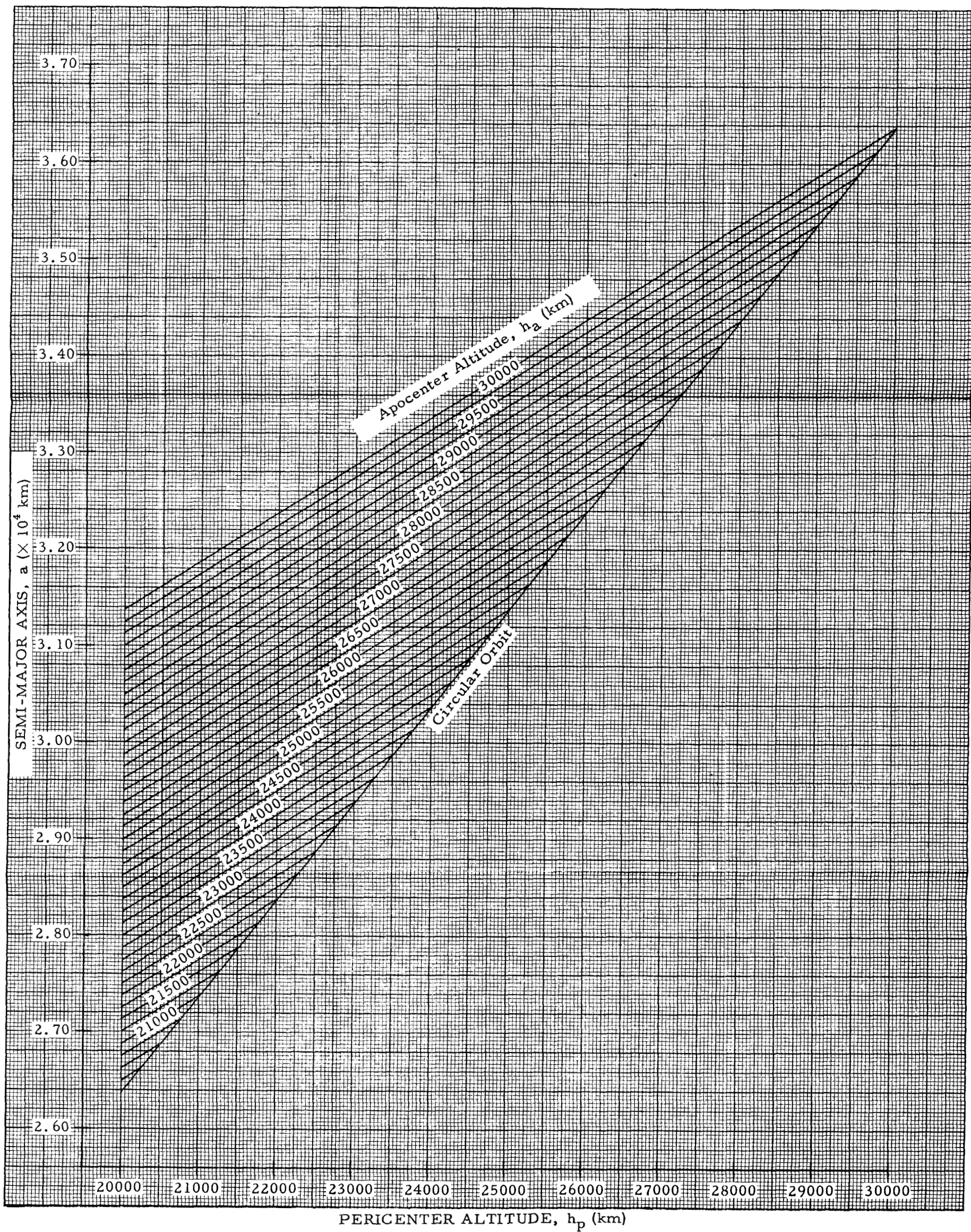


FIGURE 5e. SEMI-MAJOR AXIS VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

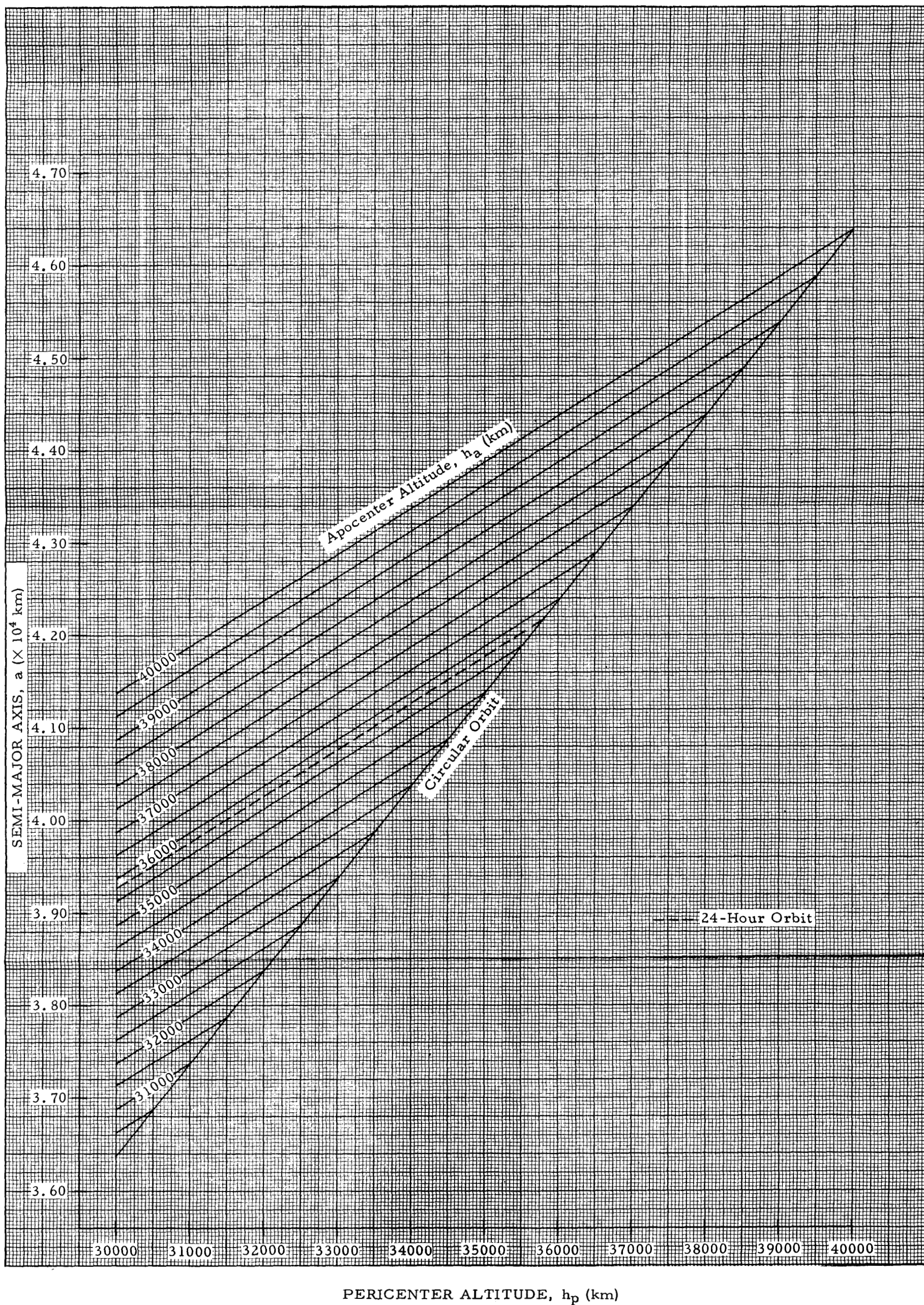


FIGURE 5f. SEMI-MAJOR AXIS VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

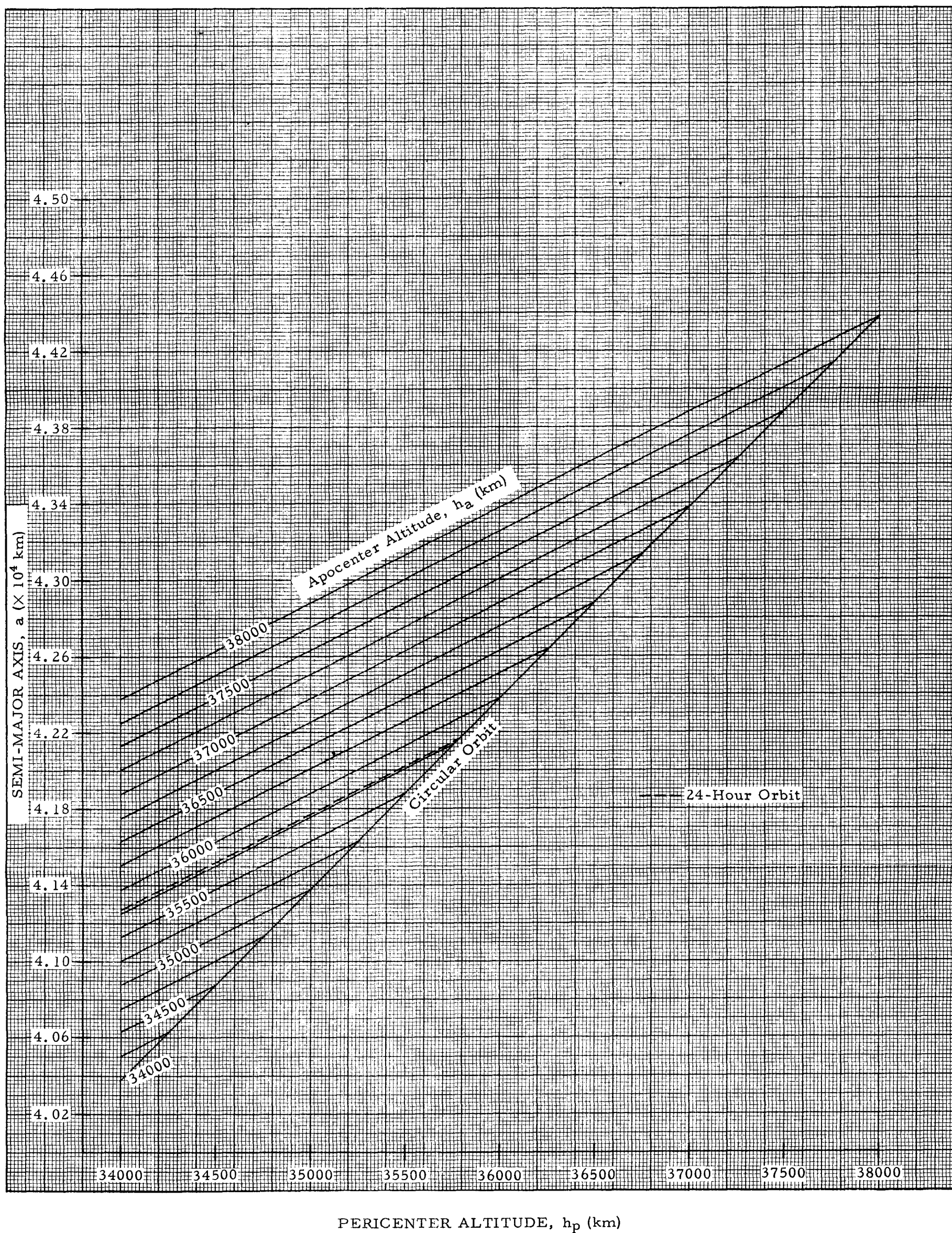


FIGURE 5g. SEMI-MAJOR AXIS VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

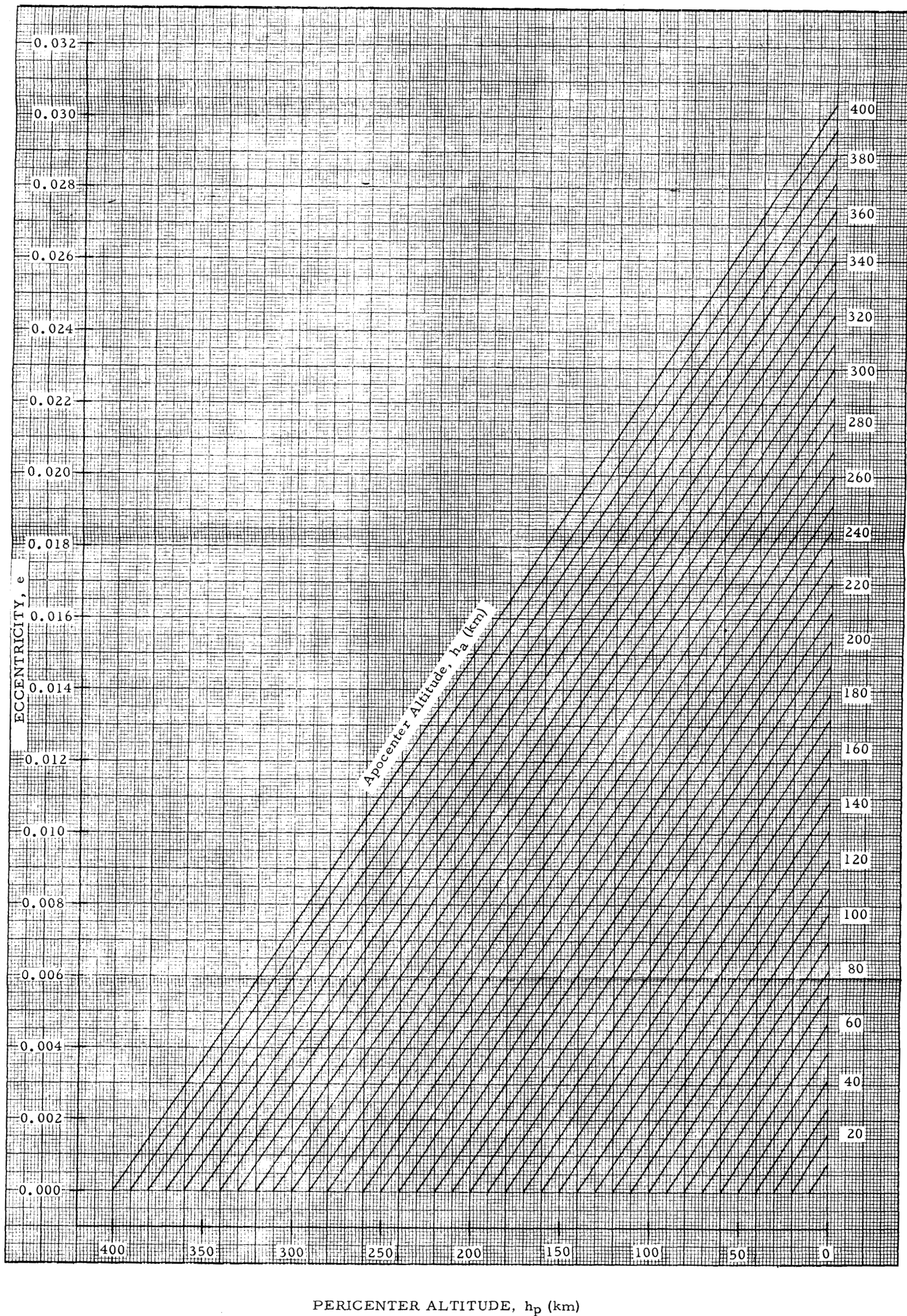


FIGURE 6a. ECCENTRICITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

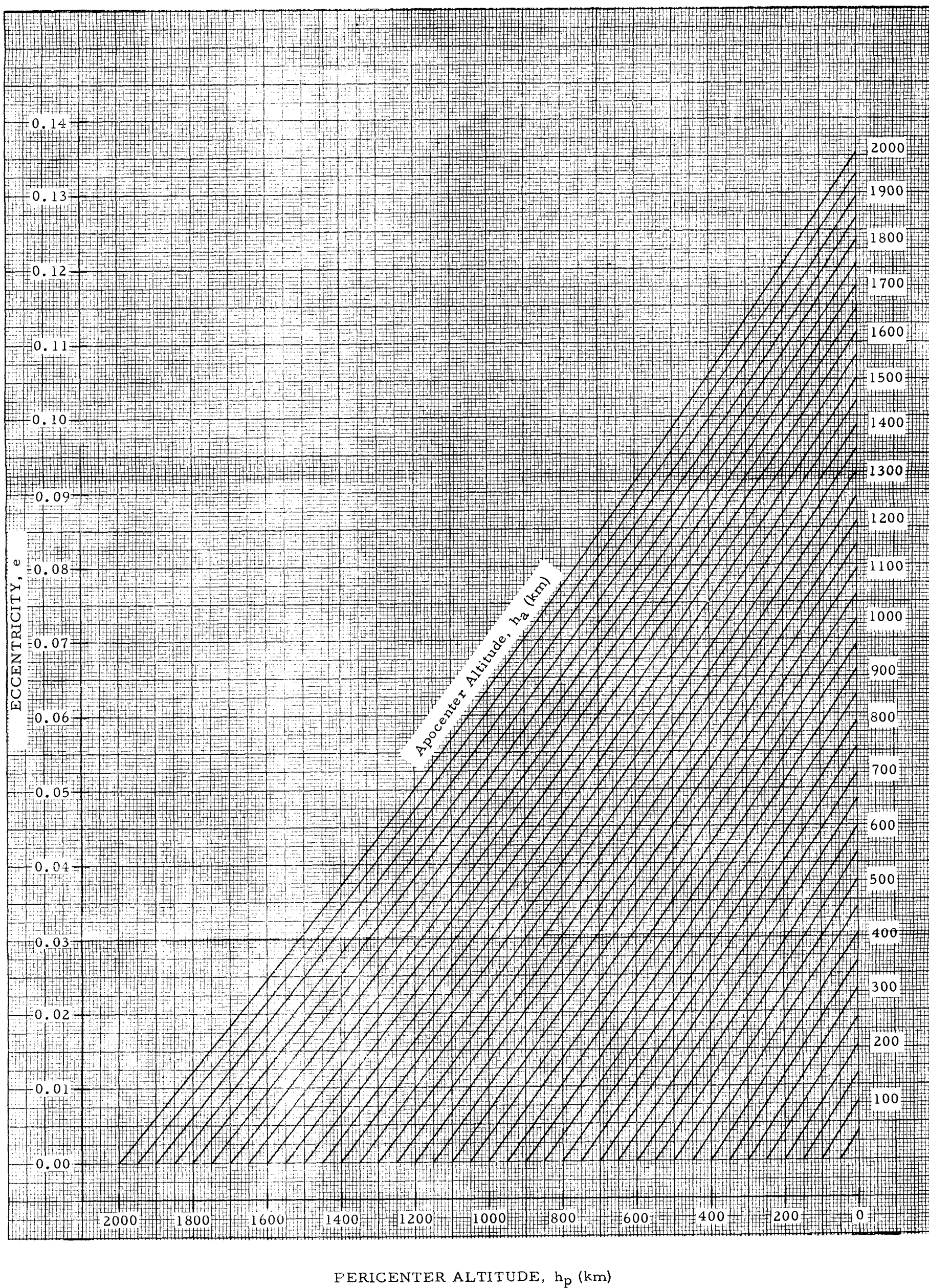


FIGURE 6b. ECCENTRICITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

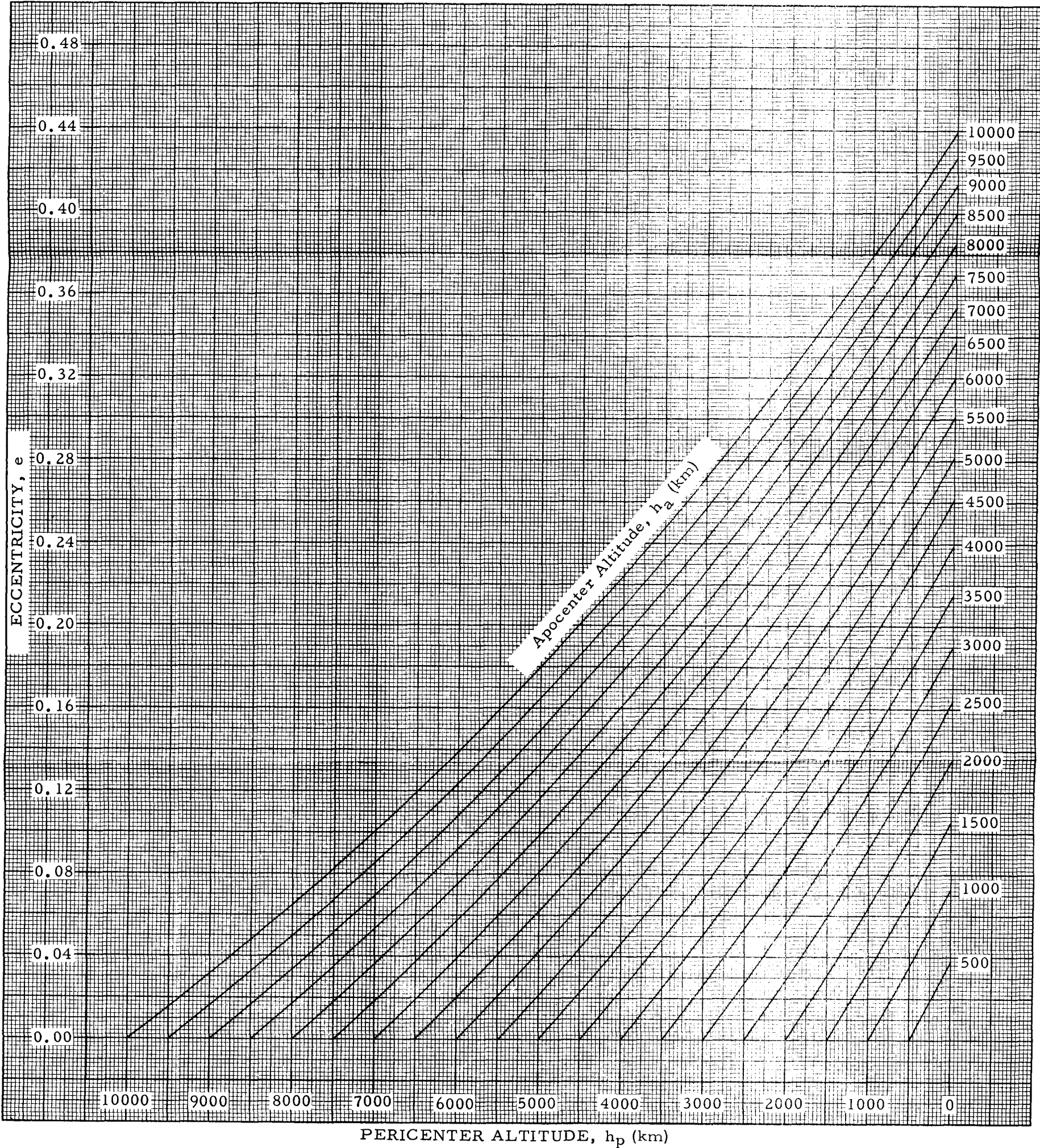


FIGURE 6c. ECCENTRICITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

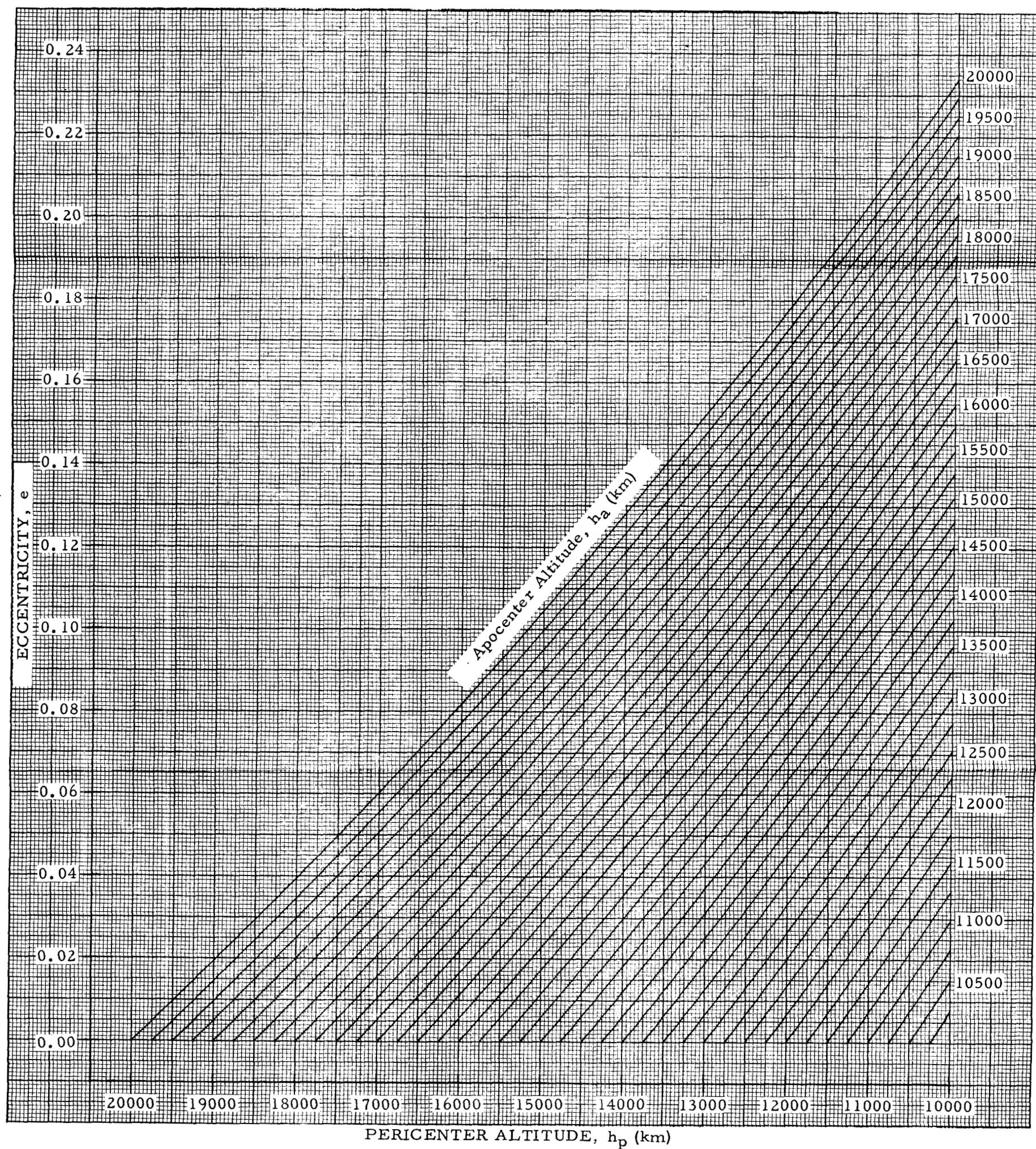


FIGURE 6d. ECCENTRICITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

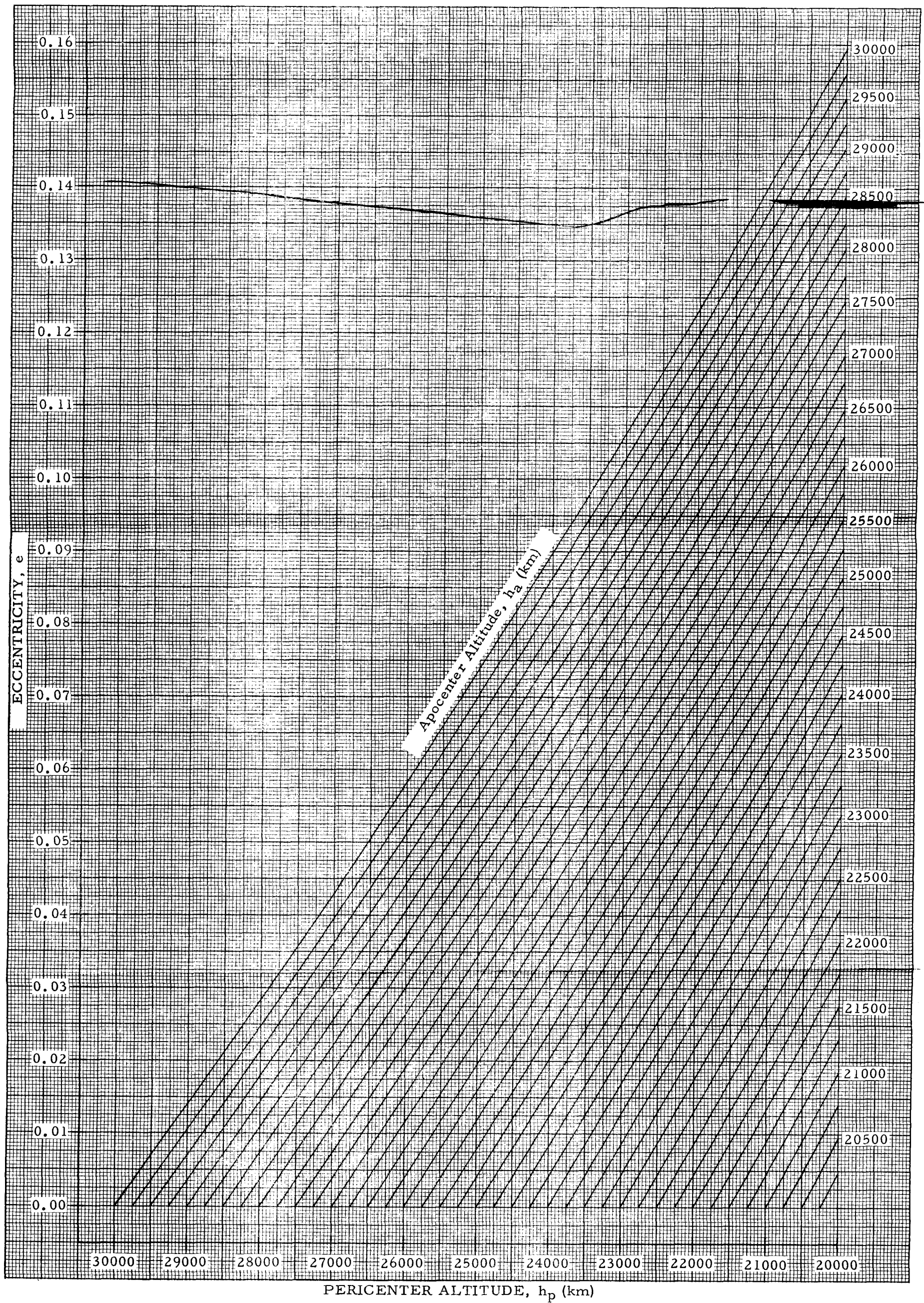


FIGURE 6e. ECCENTRICITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

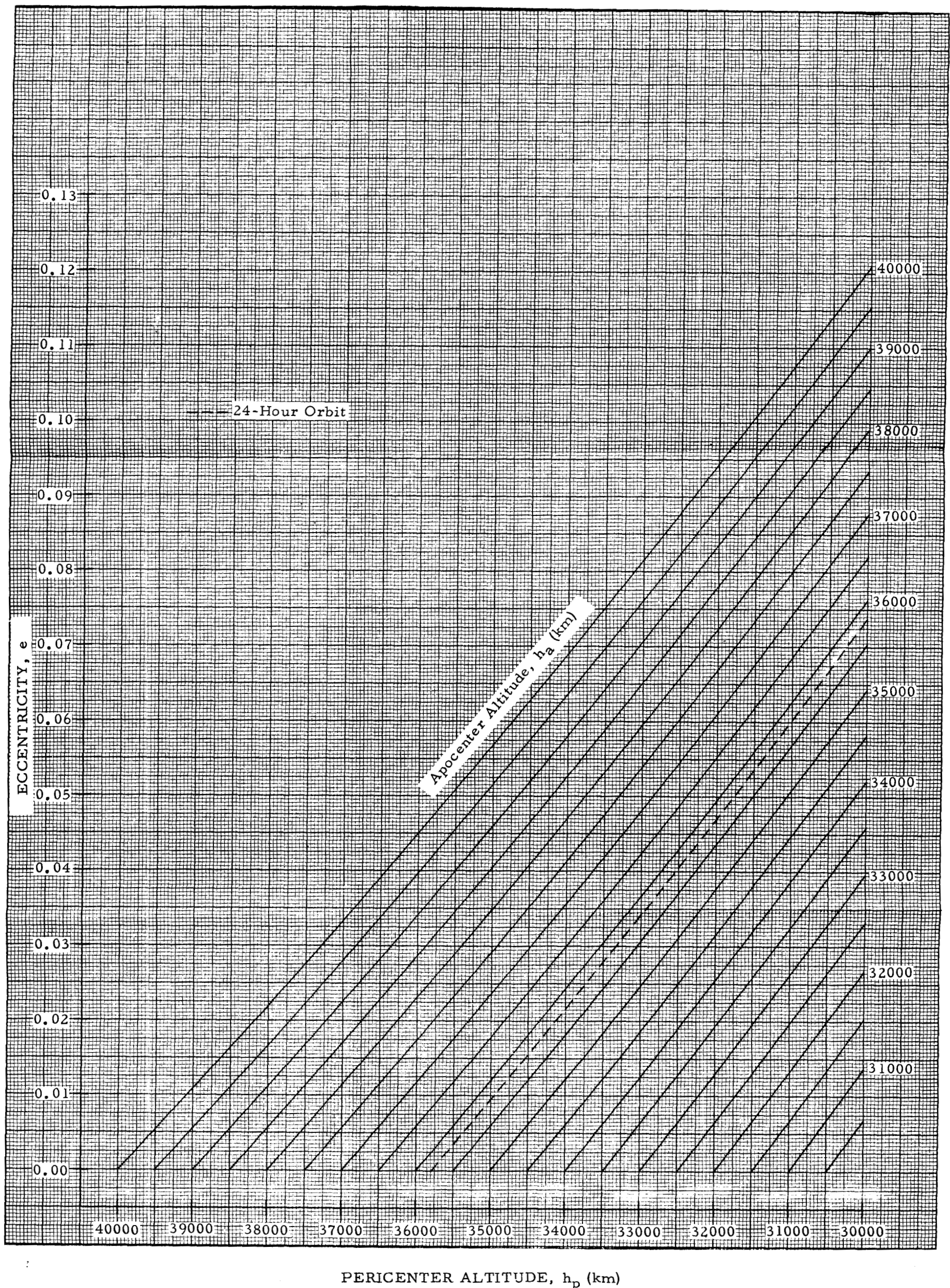


FIGURE 6f. ECCENTRICITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

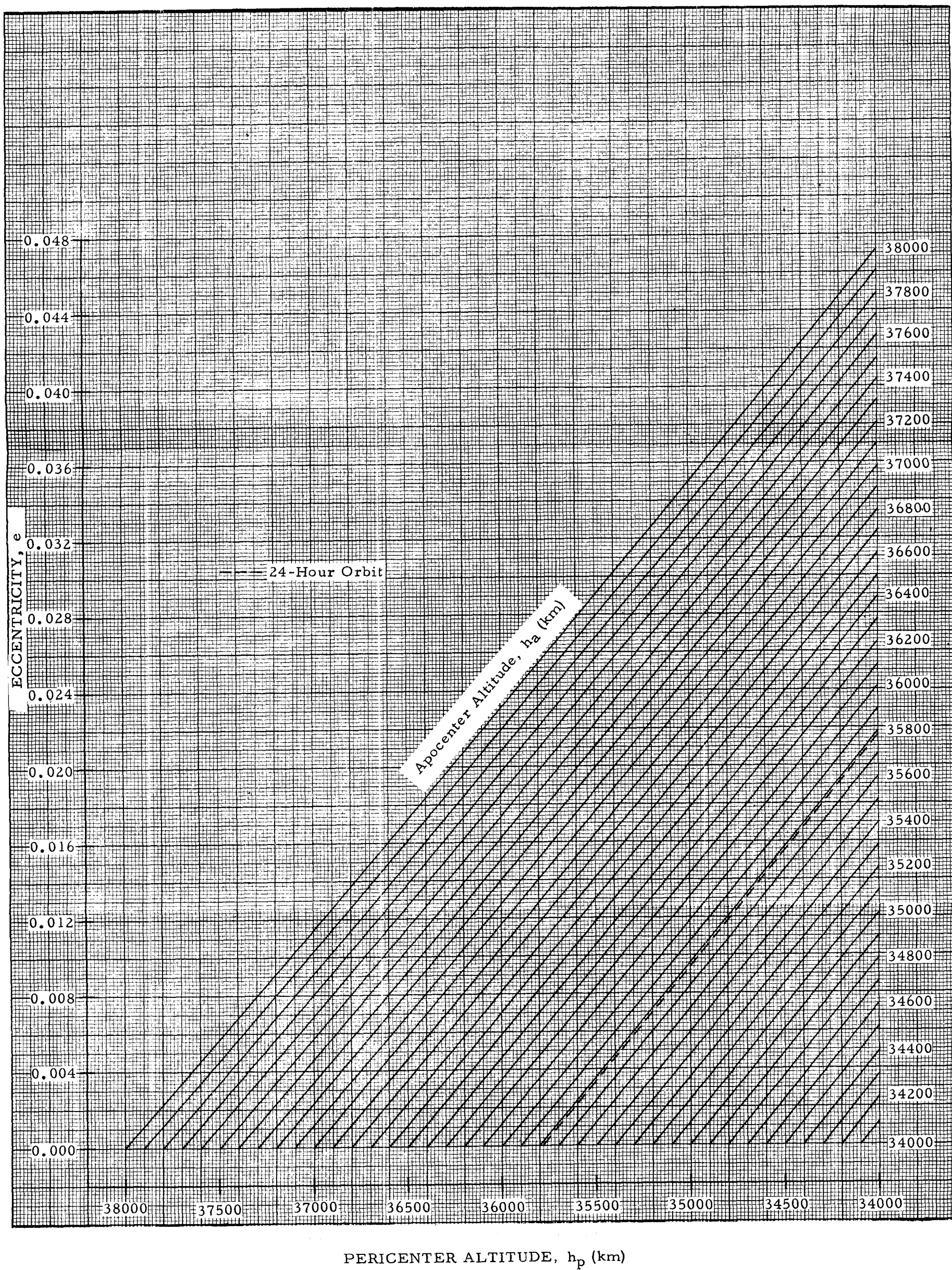


FIGURE 6g. ECCENTRICITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

ILLUSTRATIONS

SECTION B

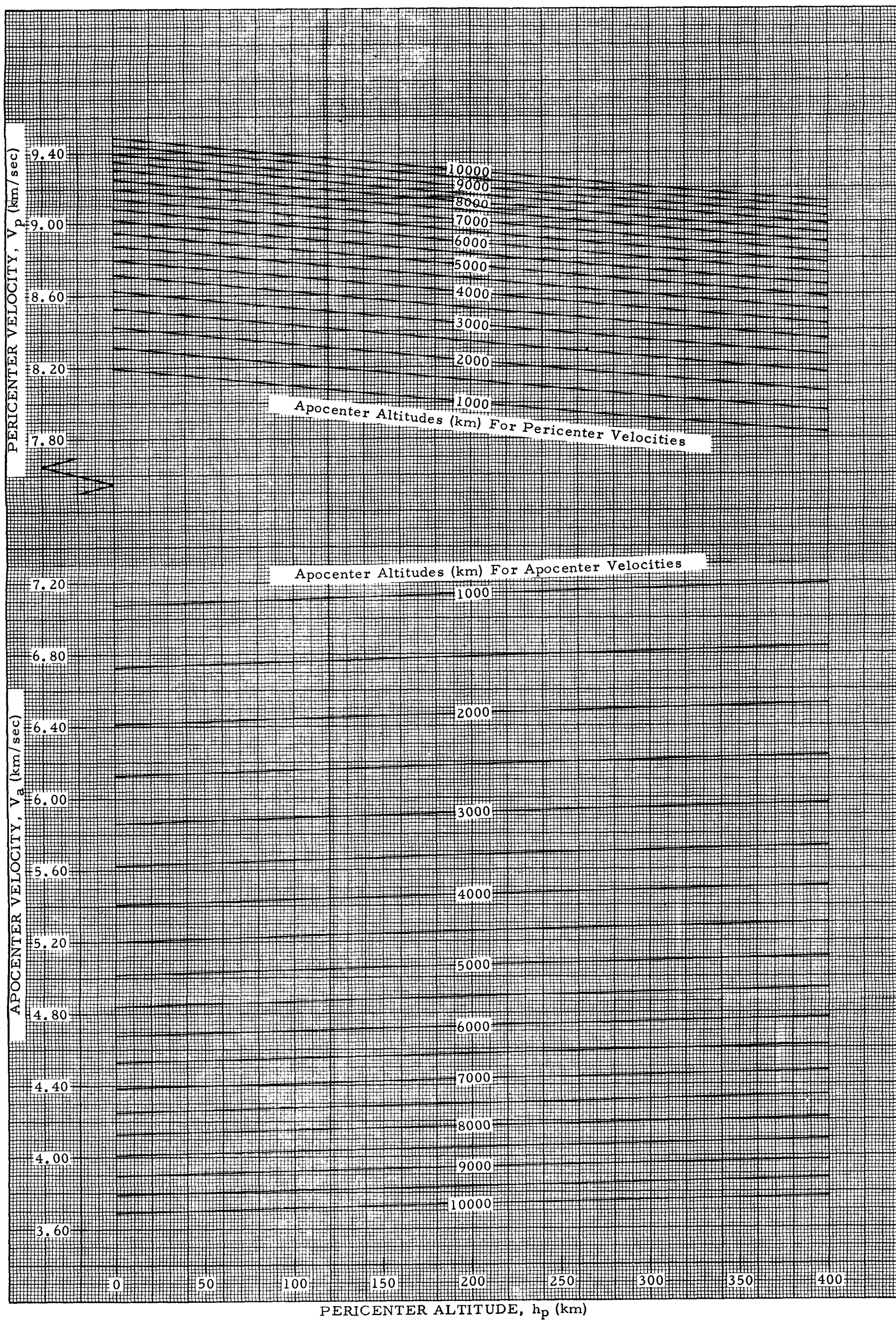


FIGURE 1a. VELOCITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE FOR PERICENTER VELOCITIES AND APOCENTER ALTITUDE FOR APOCENTER VELOCITIES AS PARAMETERS

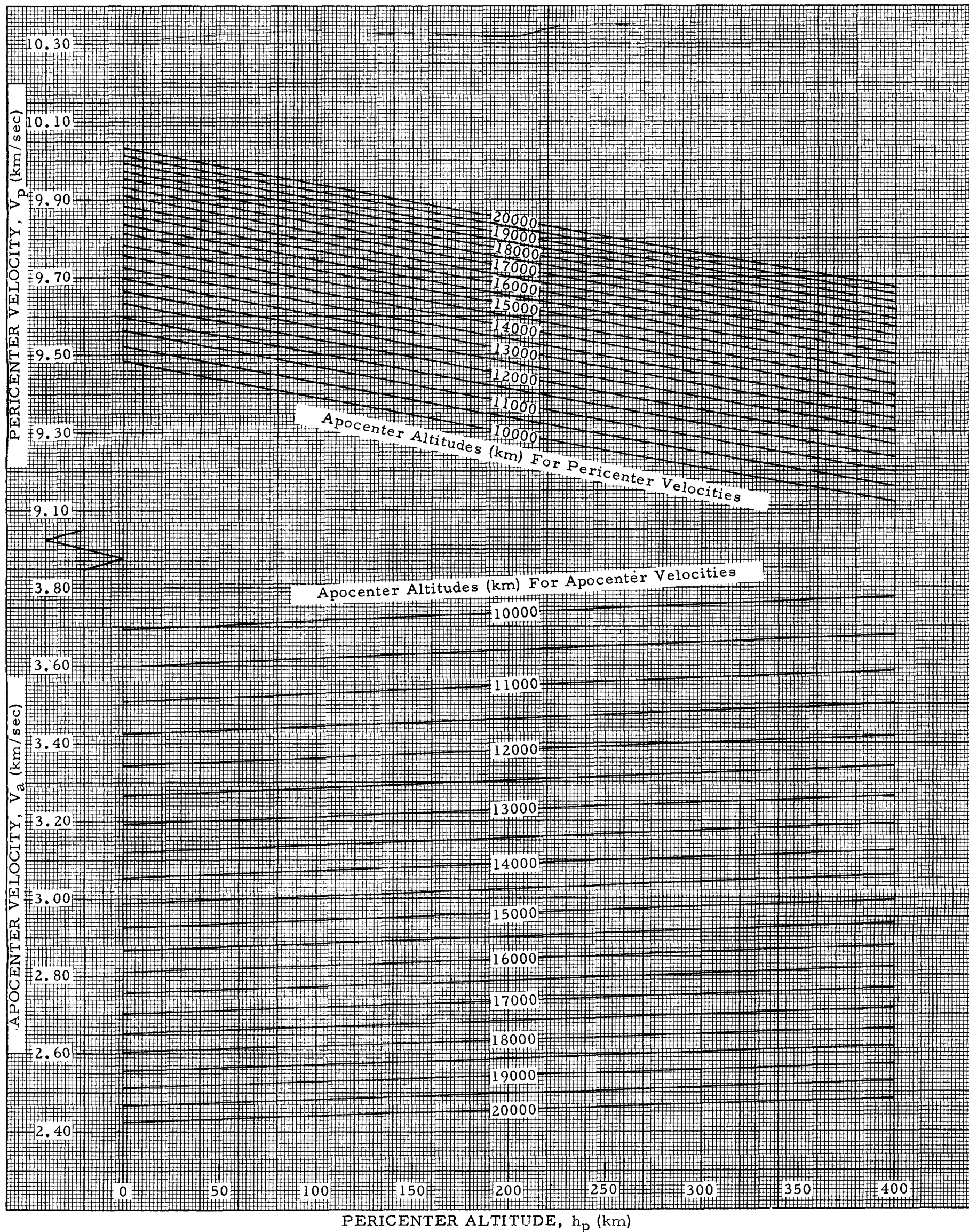


FIGURE 1b. VELOCITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE FOR PERICENTER VELOCITIES AND APOCENTER ALTITUDE FOR APOCENTER VELOCITIES AS PARAMETERS

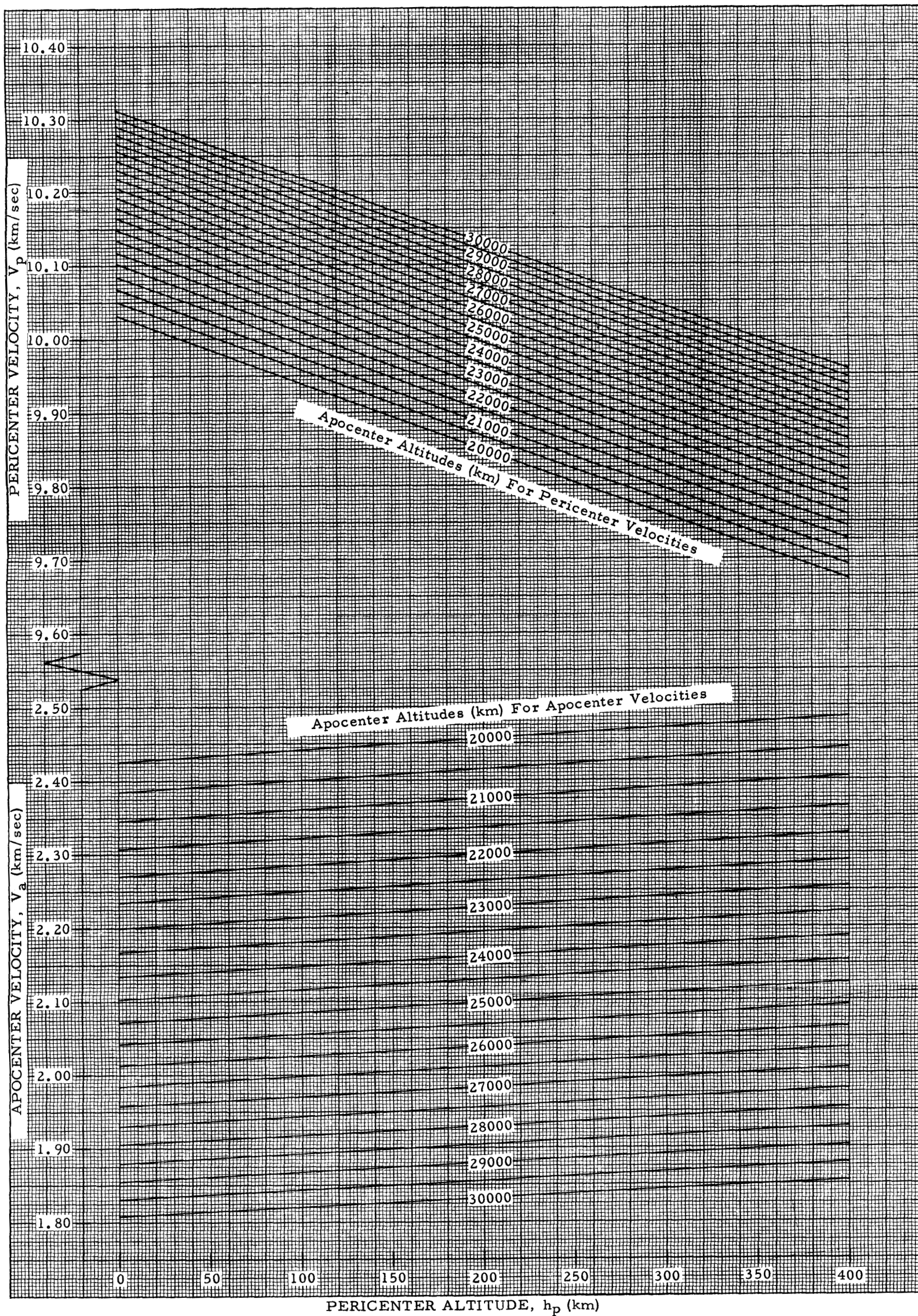


FIGURE 1c. VELOCITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE FOR PERICENTER VELOCITIES AND APOCENTER ALTITUDE FOR APOCENTER VELOCITIES AS PARAMETERS

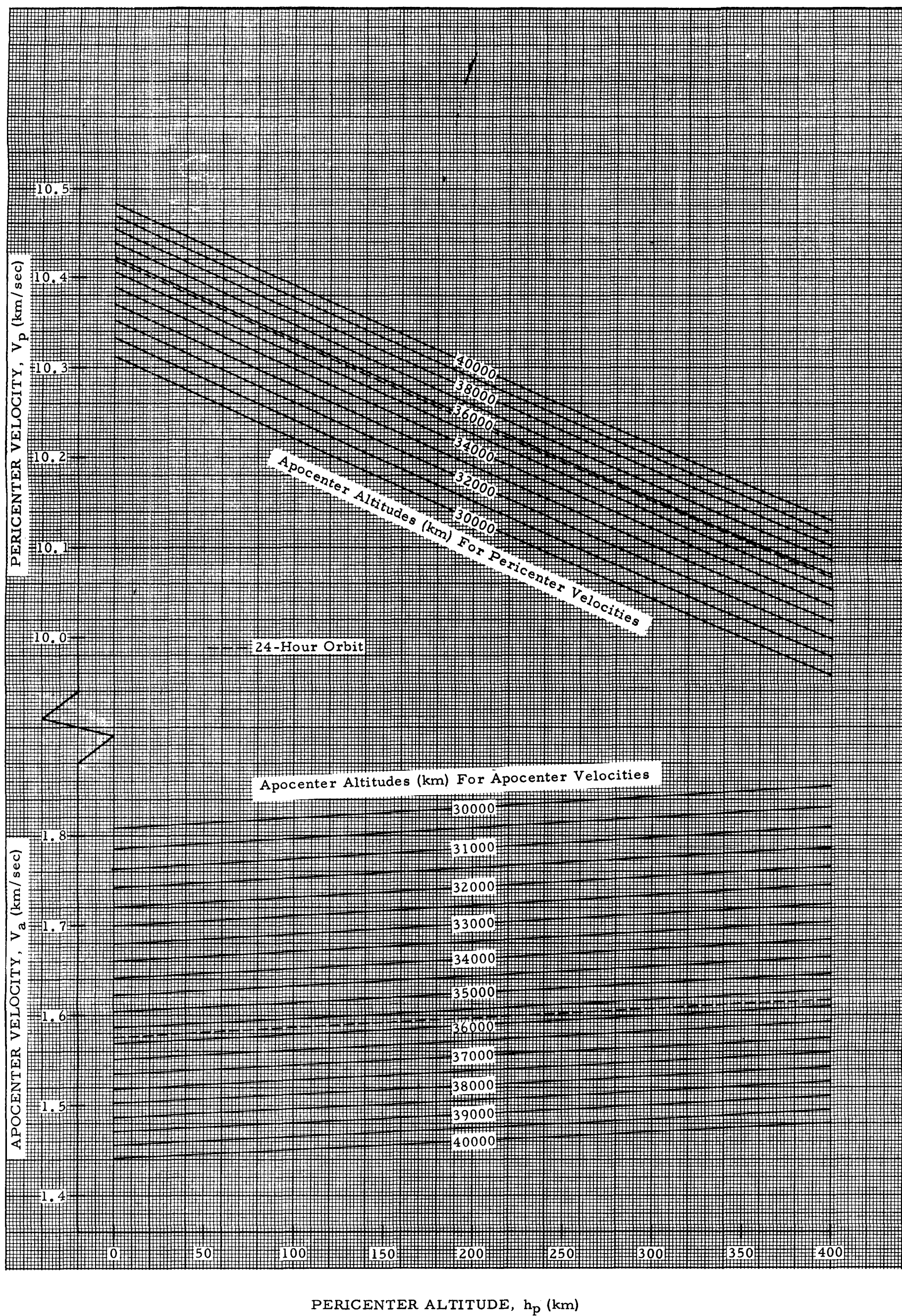


FIGURE 1d. VELOCITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE FOR PERICENTER VELOCITIES AND APOCENTER ALTITUDE FOR APOCENTER VELOCITIES AS PARAMETERS

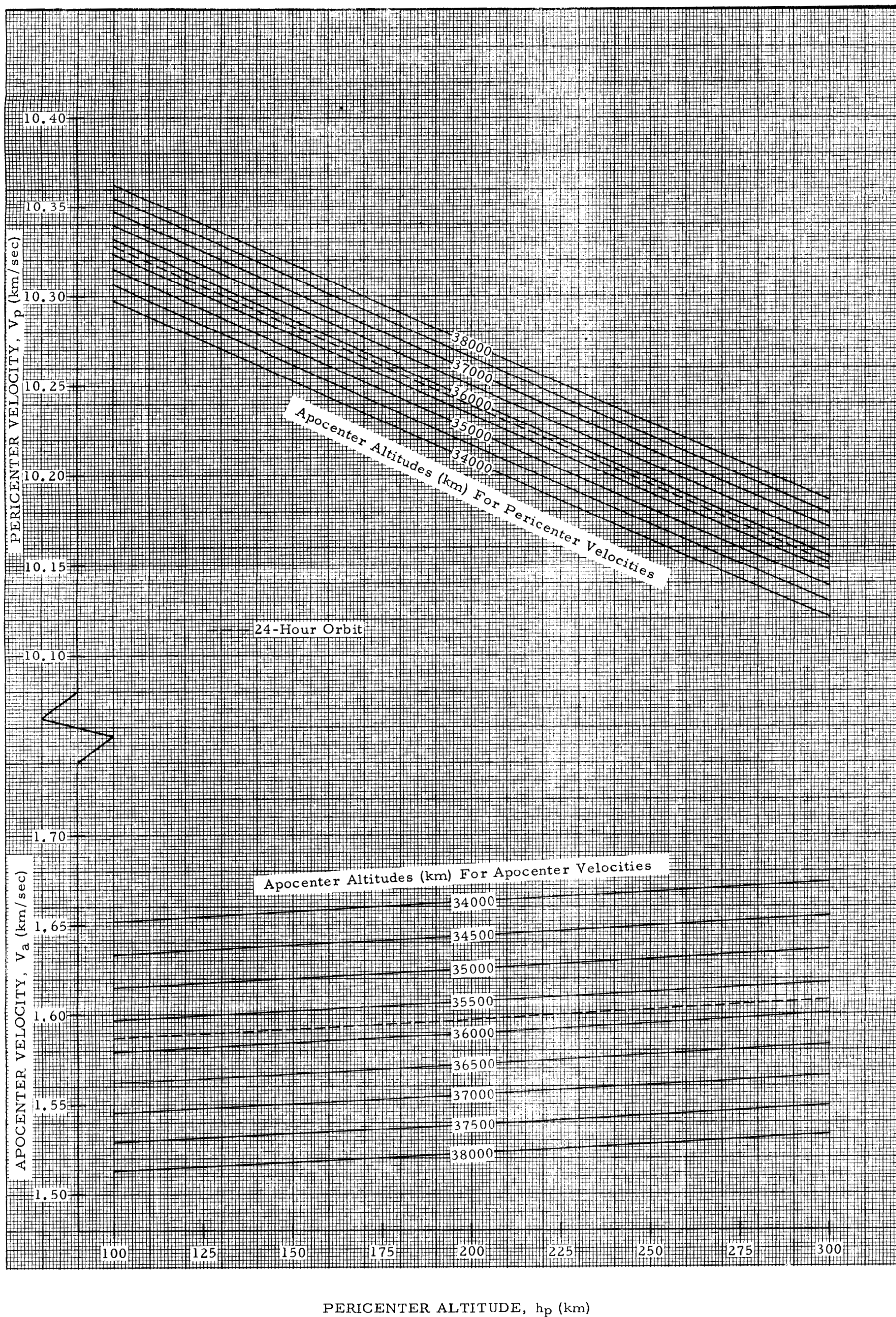


FIGURE 1e. VELOCITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE FOR PERICENTER VELOCITIES AND APOCENTER ALTITUDE FOR APOCENTER VELOCITIES AS PARAMETERS

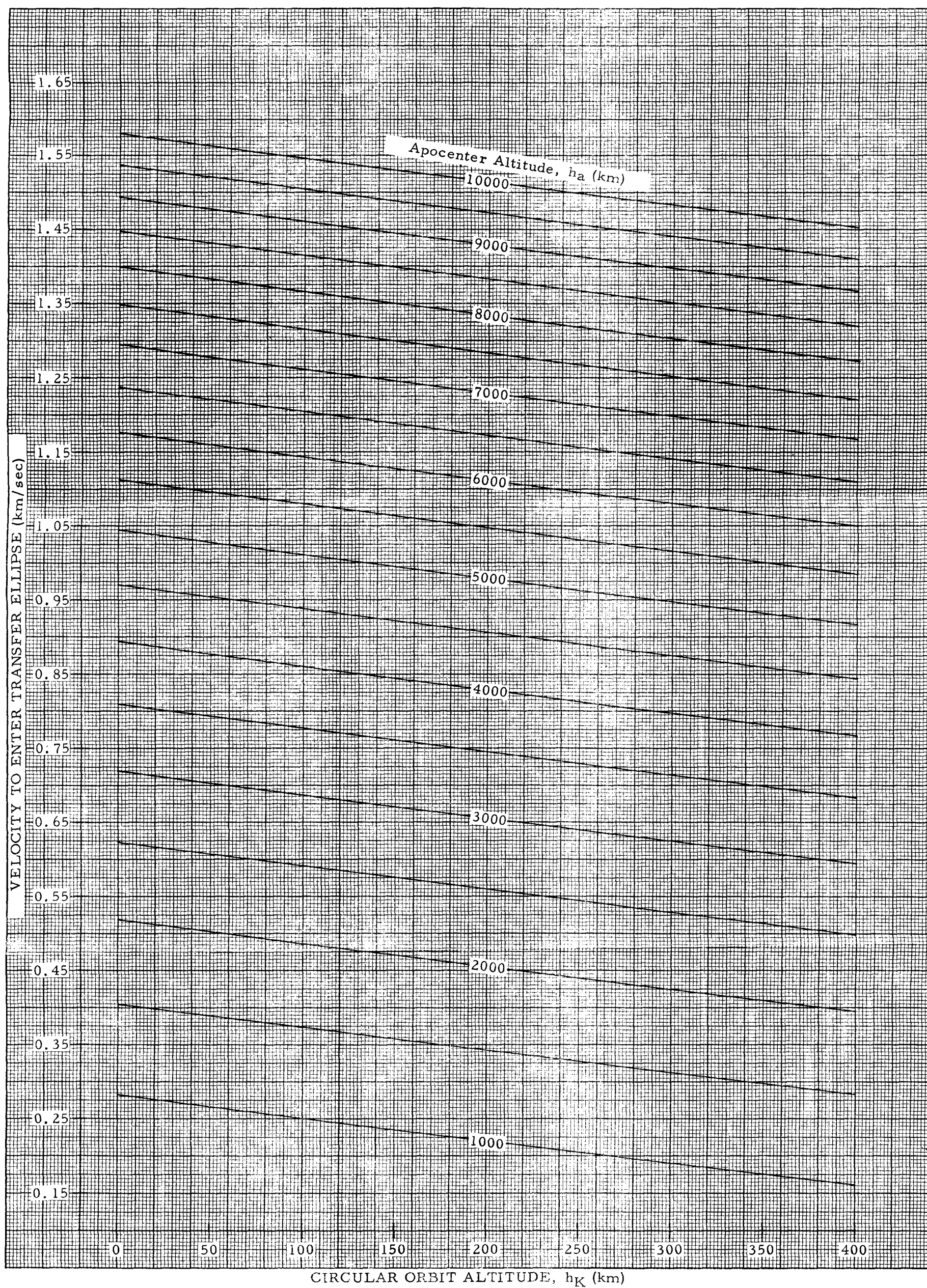


FIGURE 2a. VELOCITY REQUIRED FOR TRANSFER FROM A CIRCULAR TO AN ECCENTRIC ORBIT VERSUS CIRCULAR ORBIT ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

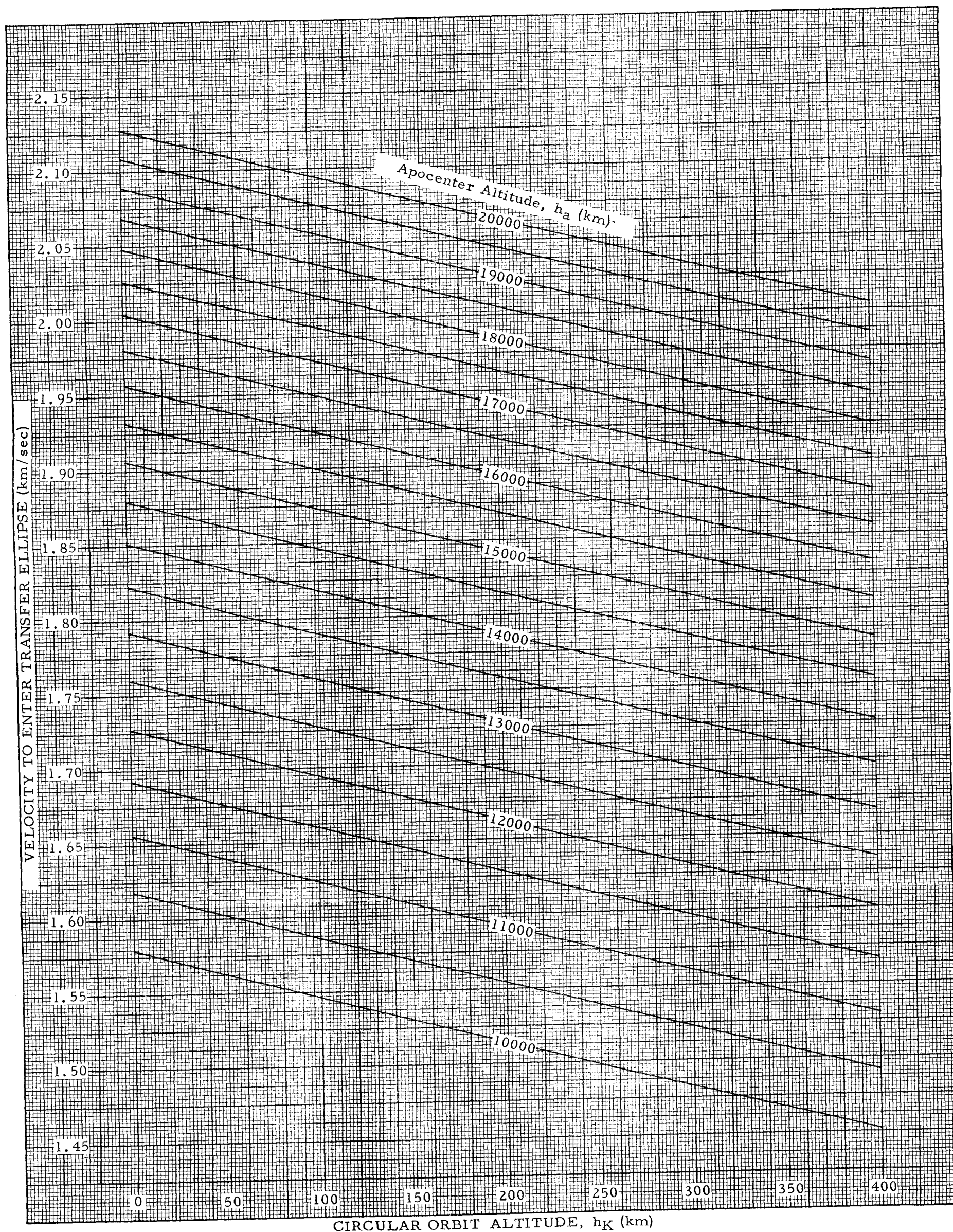


FIGURE 2b. VELOCITY REQUIRED FOR TRANSFER FROM A CIRCULAR TO AN ECCENTRIC ORBIT
VERSUS CIRCULAR ORBIT ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

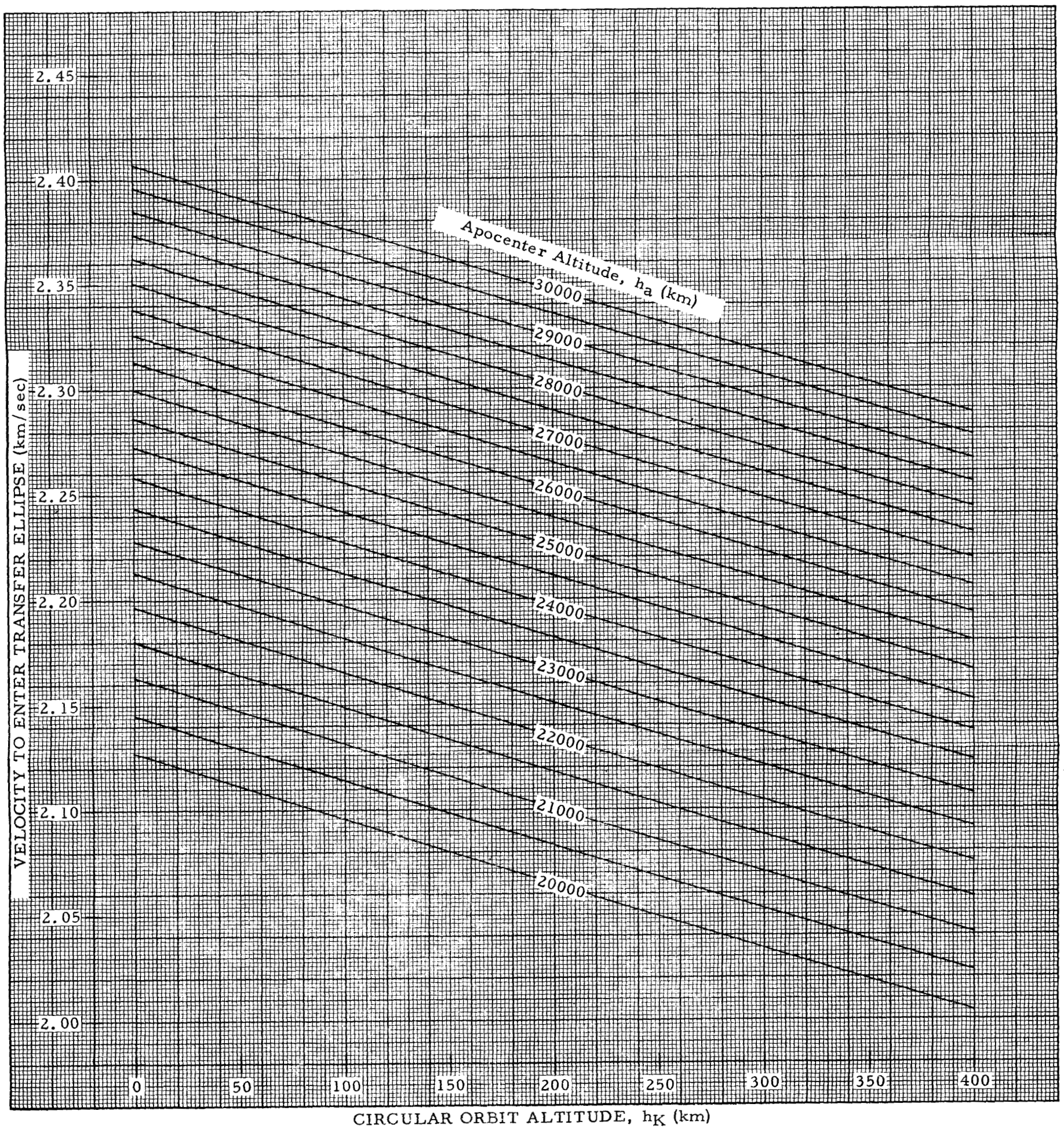


FIGURE 2c. VELOCITY REQUIRED FOR TRANSFER FROM A CIRCULAR TO AN ECCENTRIC ORBIT VERSUS CIRCULAR ORBIT ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

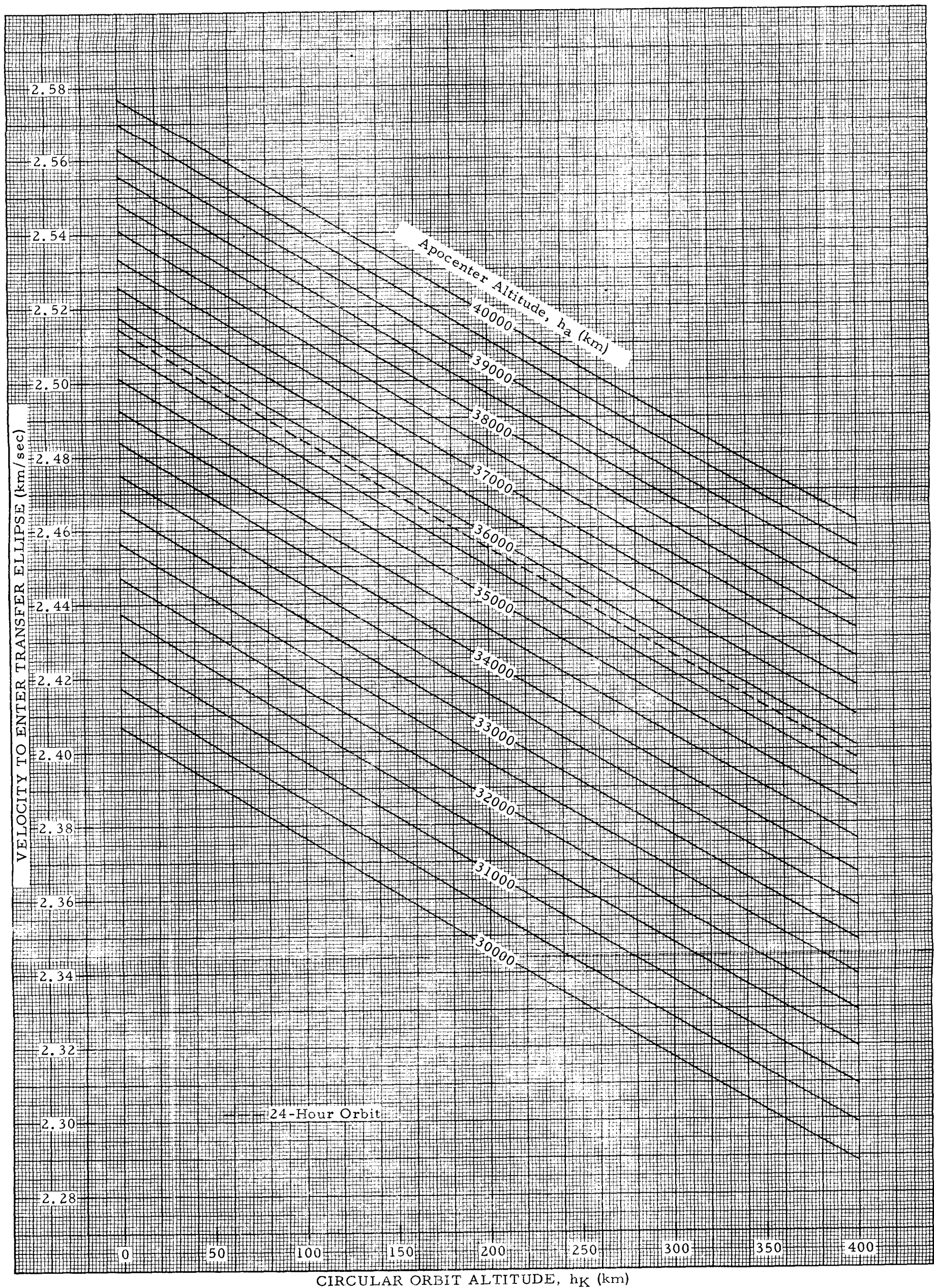


FIGURE 2d. VELOCITY REQUIRED FOR TRANSFER FROM A CIRCULAR TO AN ECCENTRIC ORBIT VERSUS CIRCULAR ORBIT ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

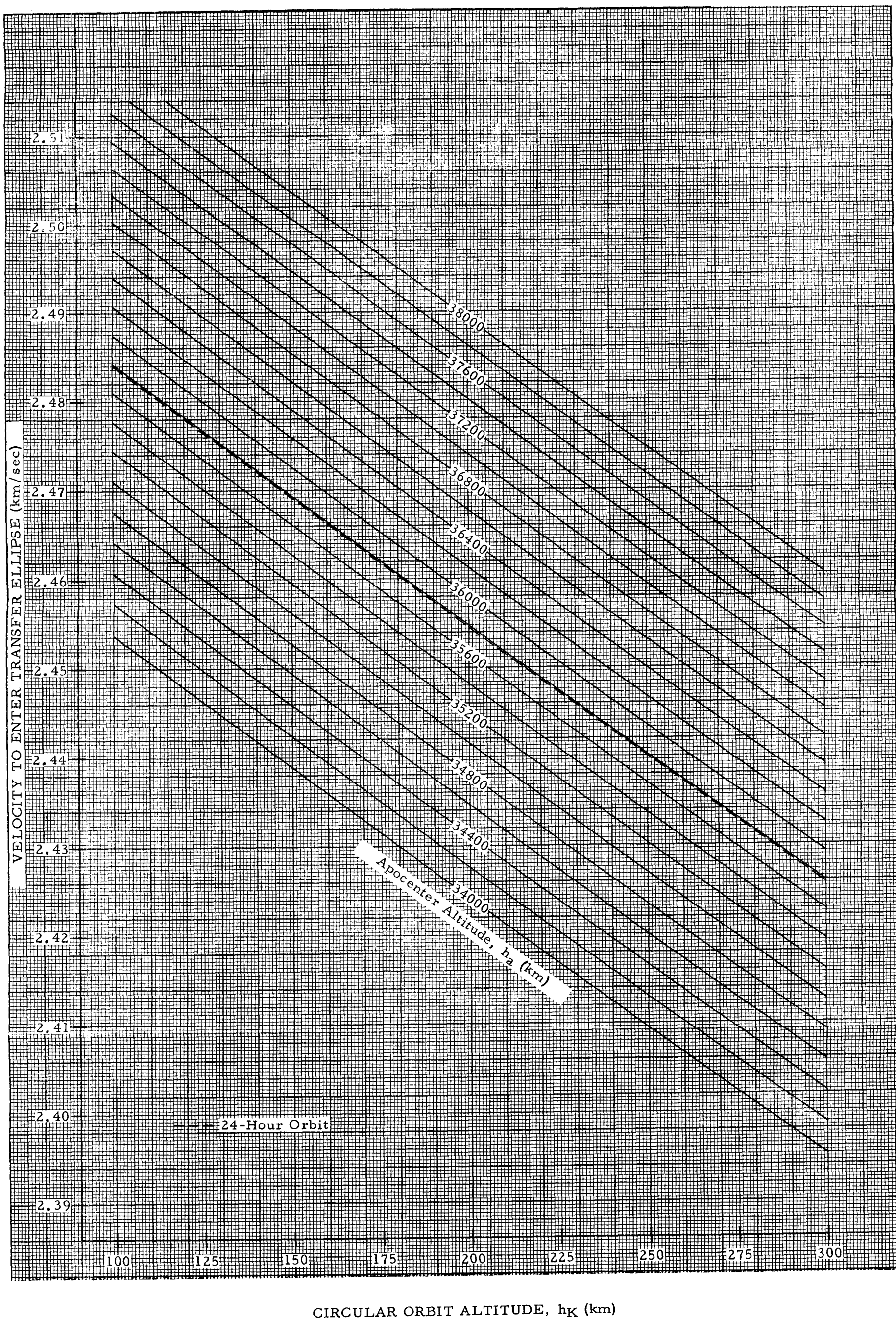


FIGURE 2e. VELOCITY REQUIRED FOR TRANSFER FROM A CIRCULAR TO AN ECCENTRIC ORBIT VERSUS CIRCULAR ORBIT ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

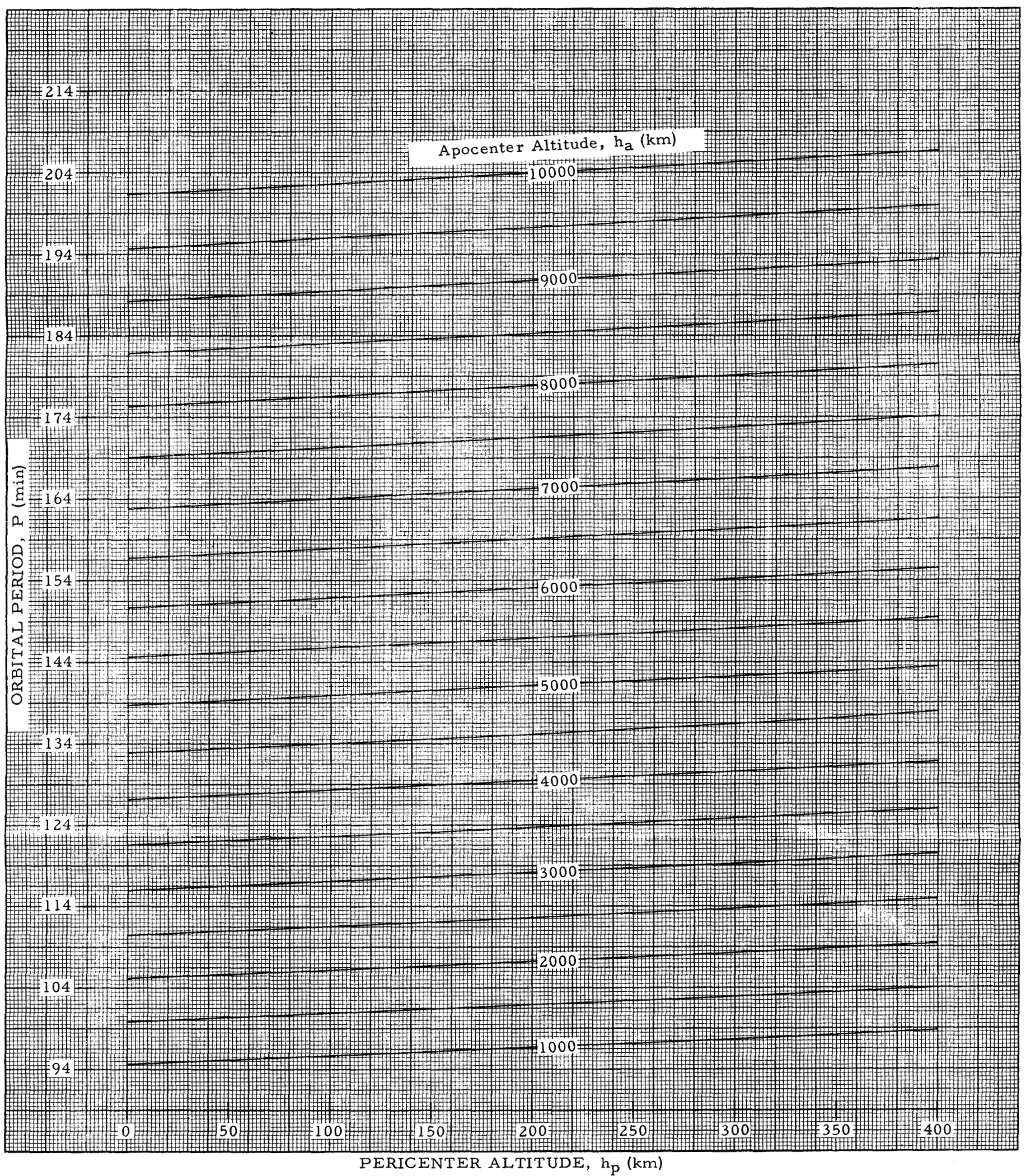


FIGURE 3a. ORBITAL PERIOD VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

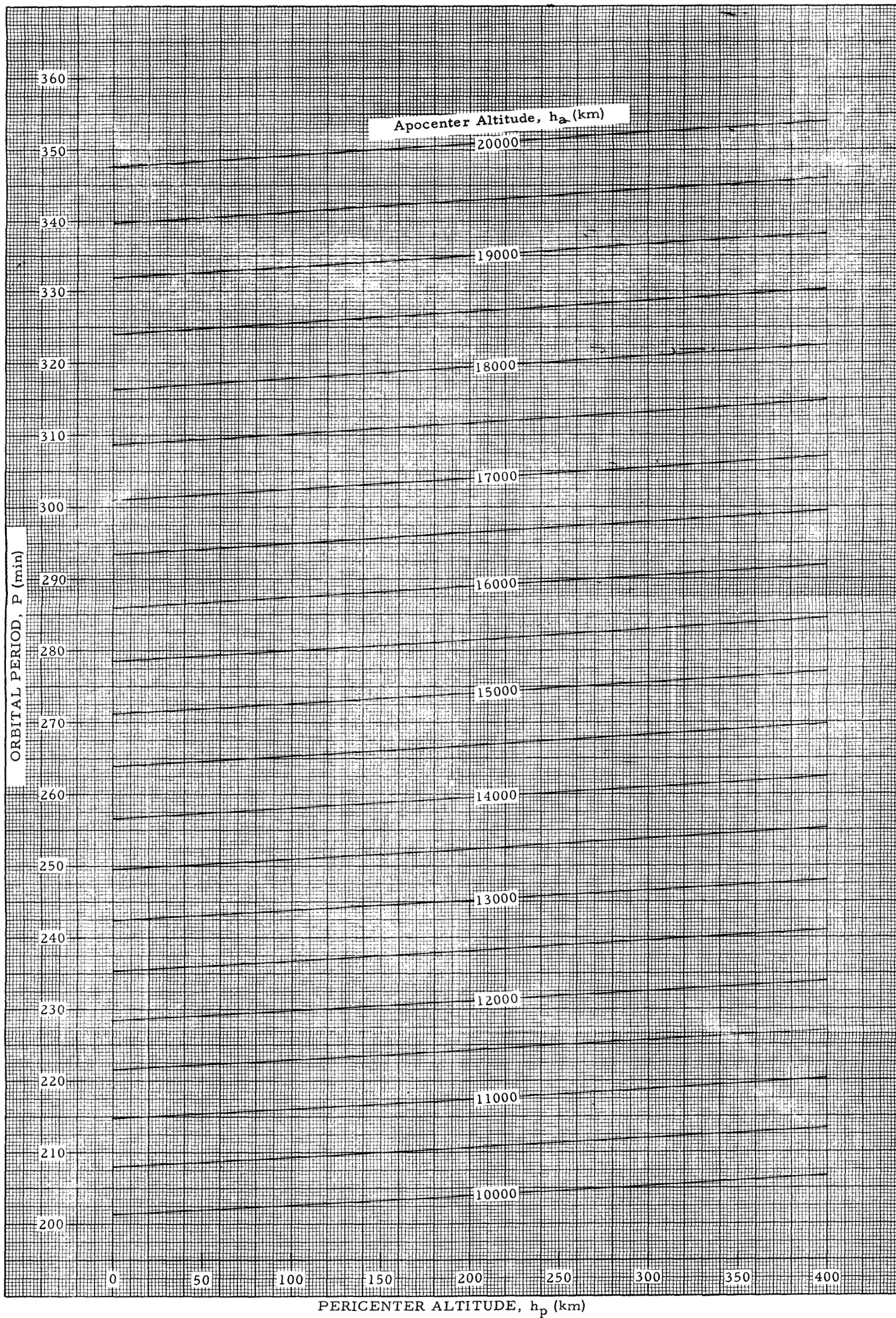


FIGURE 3b. ORBITAL PERIOD VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

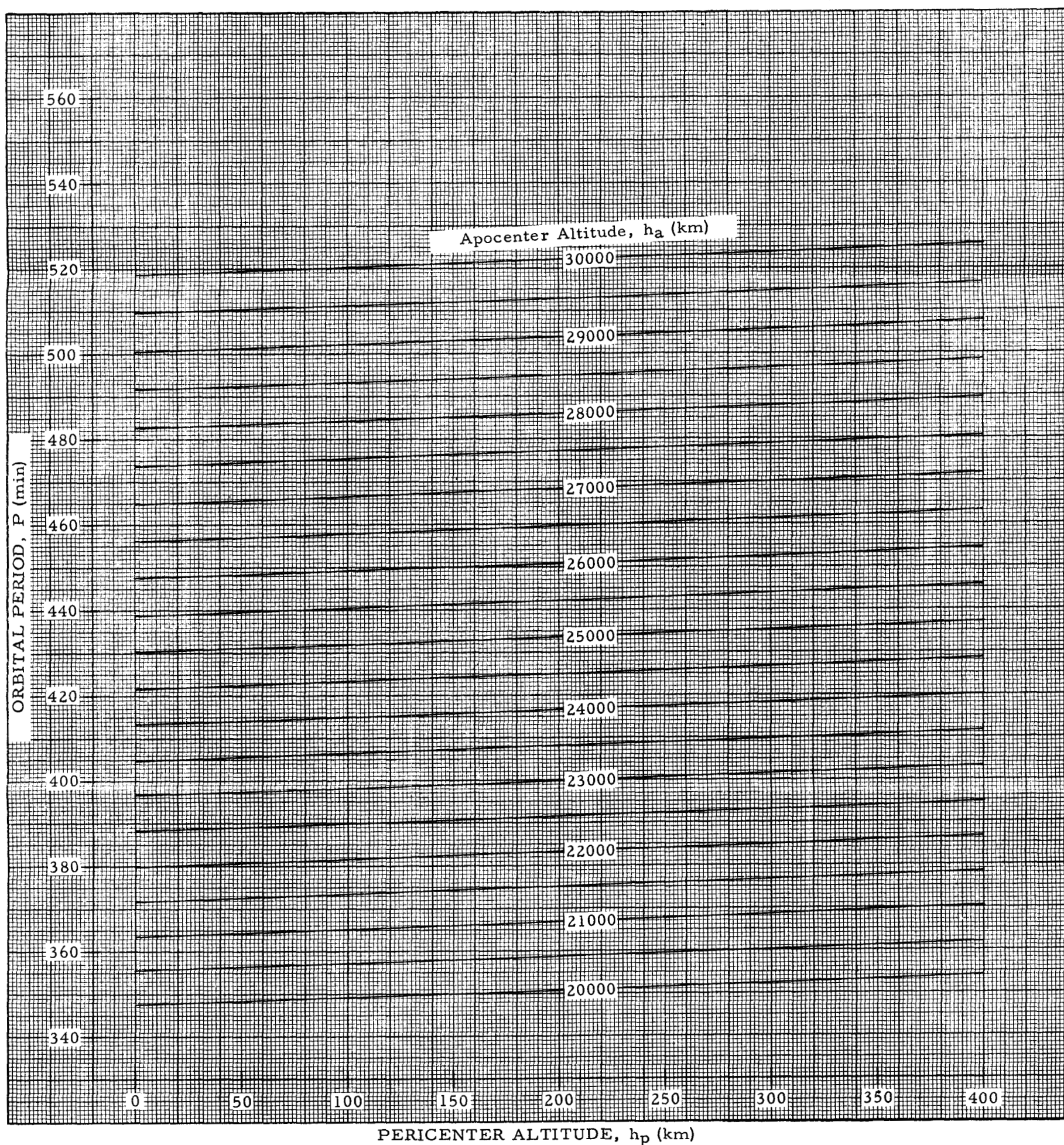


FIGURE 3c. ORBITAL PERIOD VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

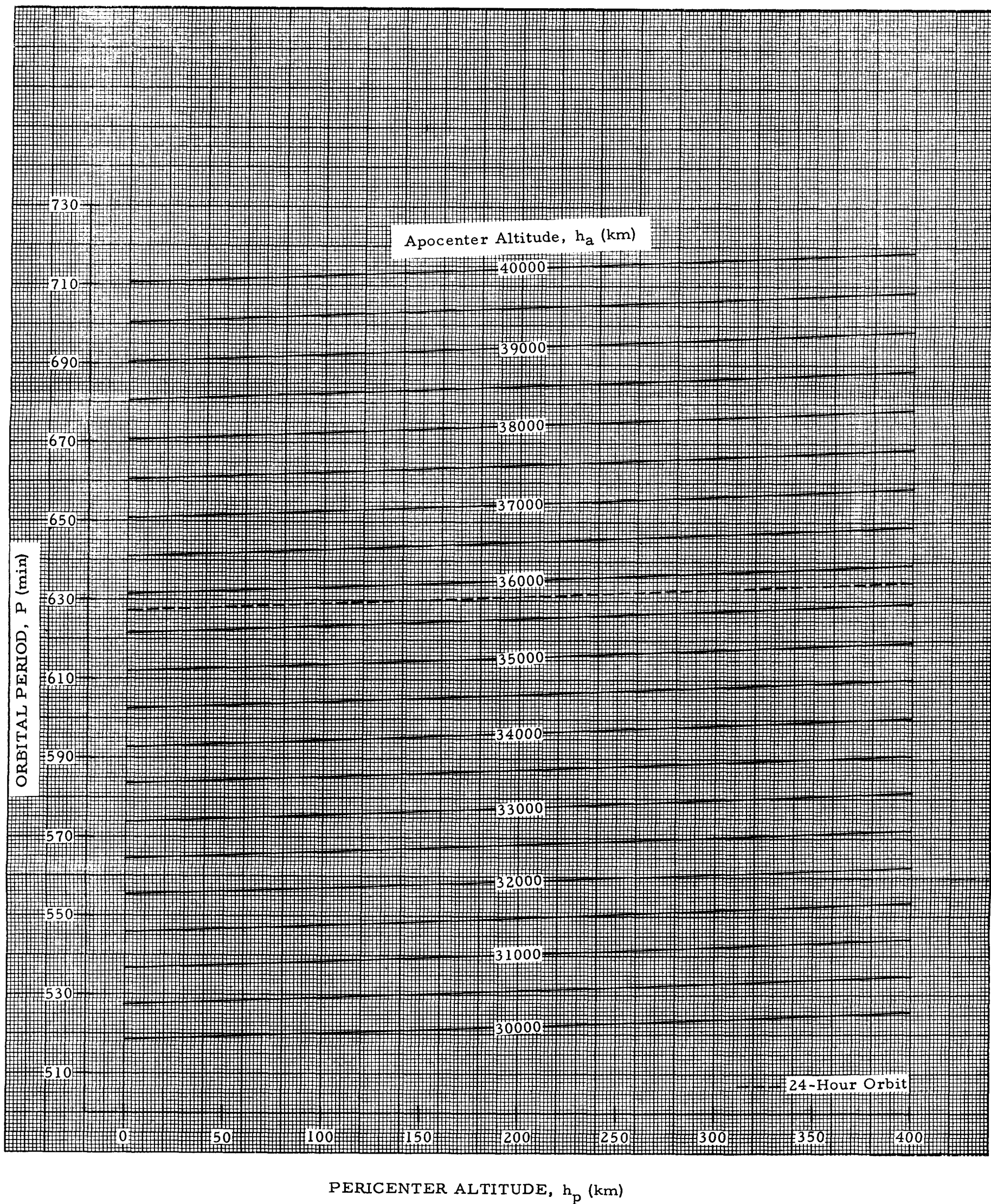


FIGURE 3d. ORBITAL PERIOD VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

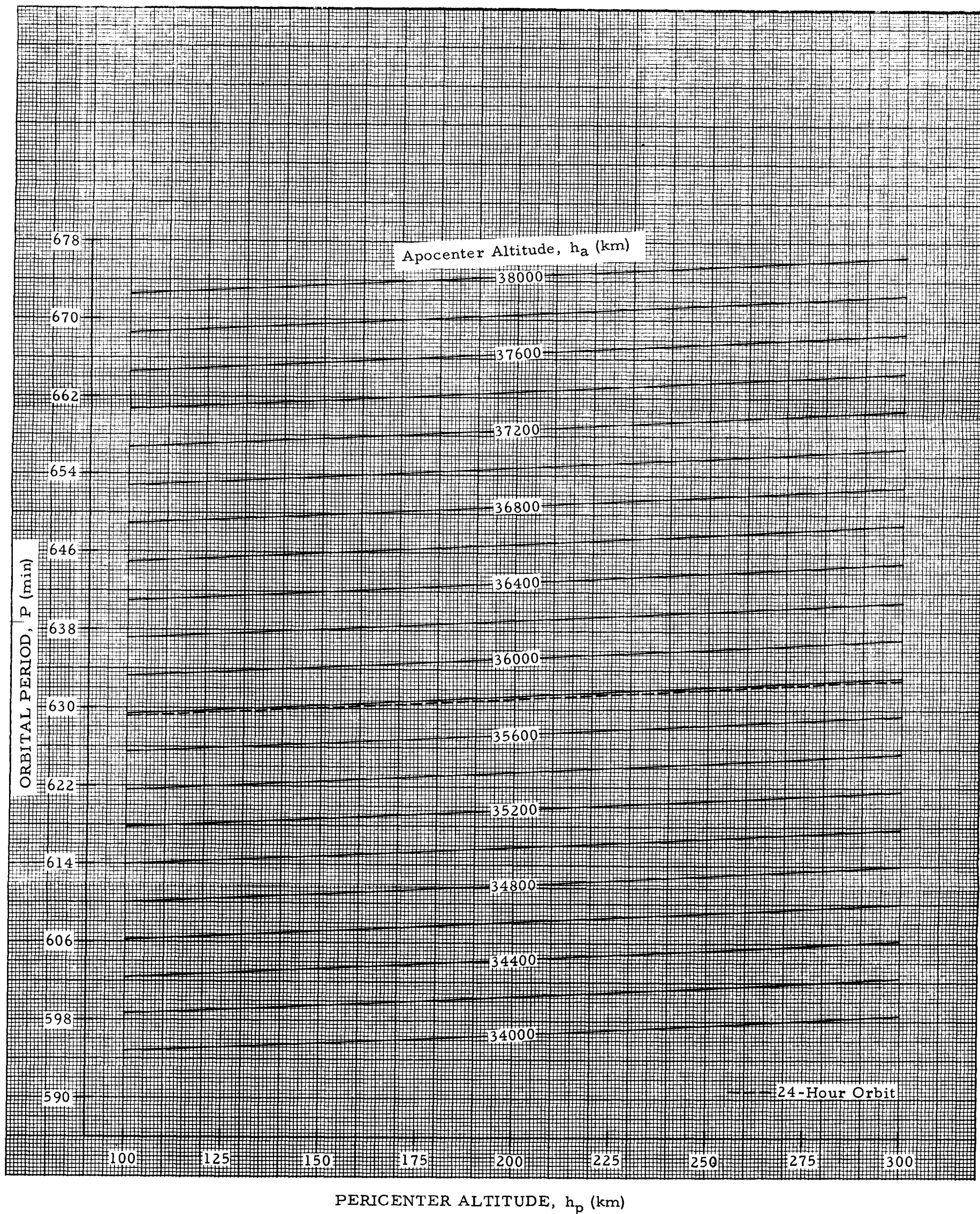


FIGURE 3e. ORBITAL PERIOD VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

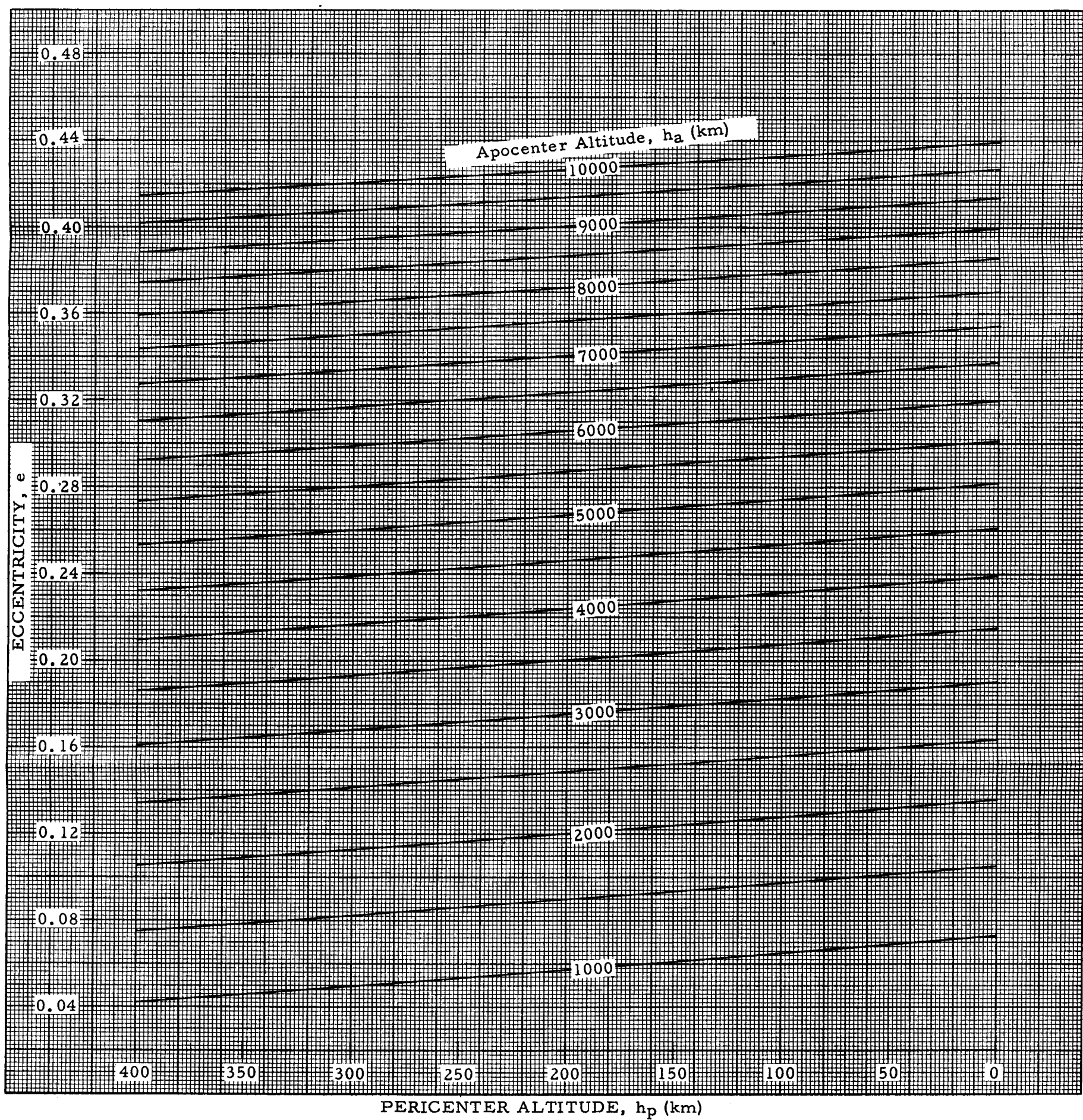


FIGURE 4a. ECCENTRICITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

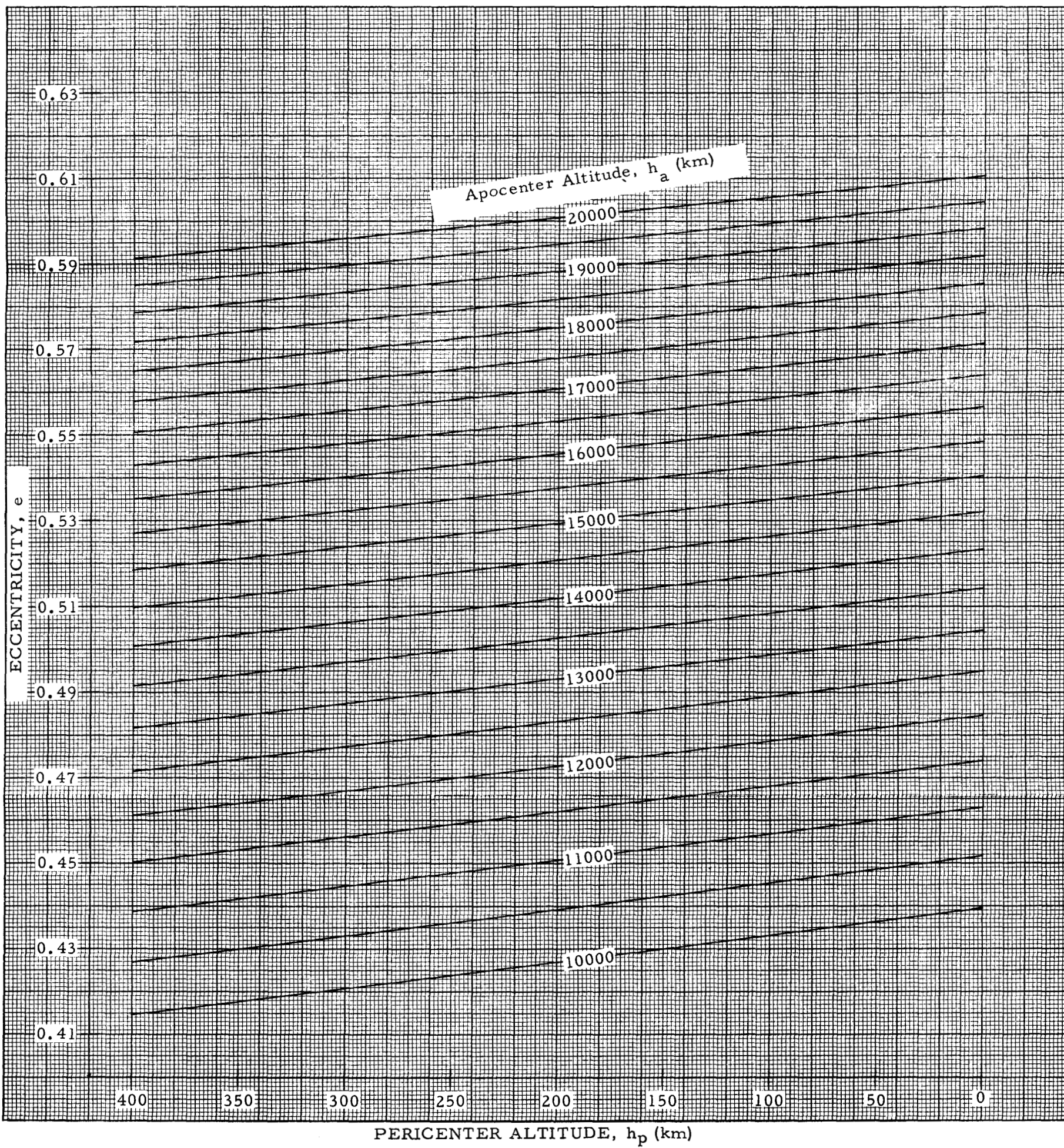


FIGURE 4b. ECCENTRICITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

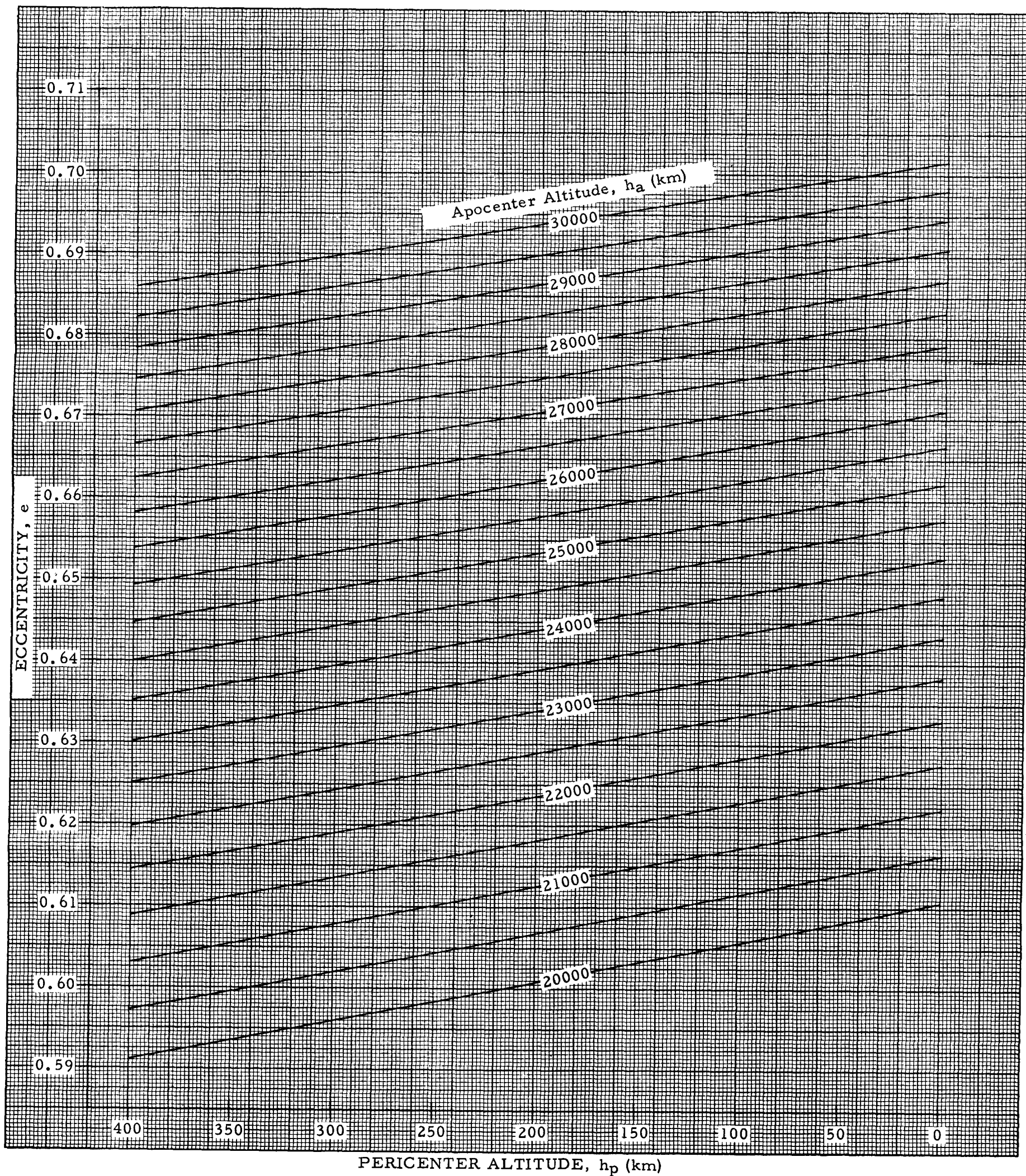


FIGURE 4c. ECCENTRICITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

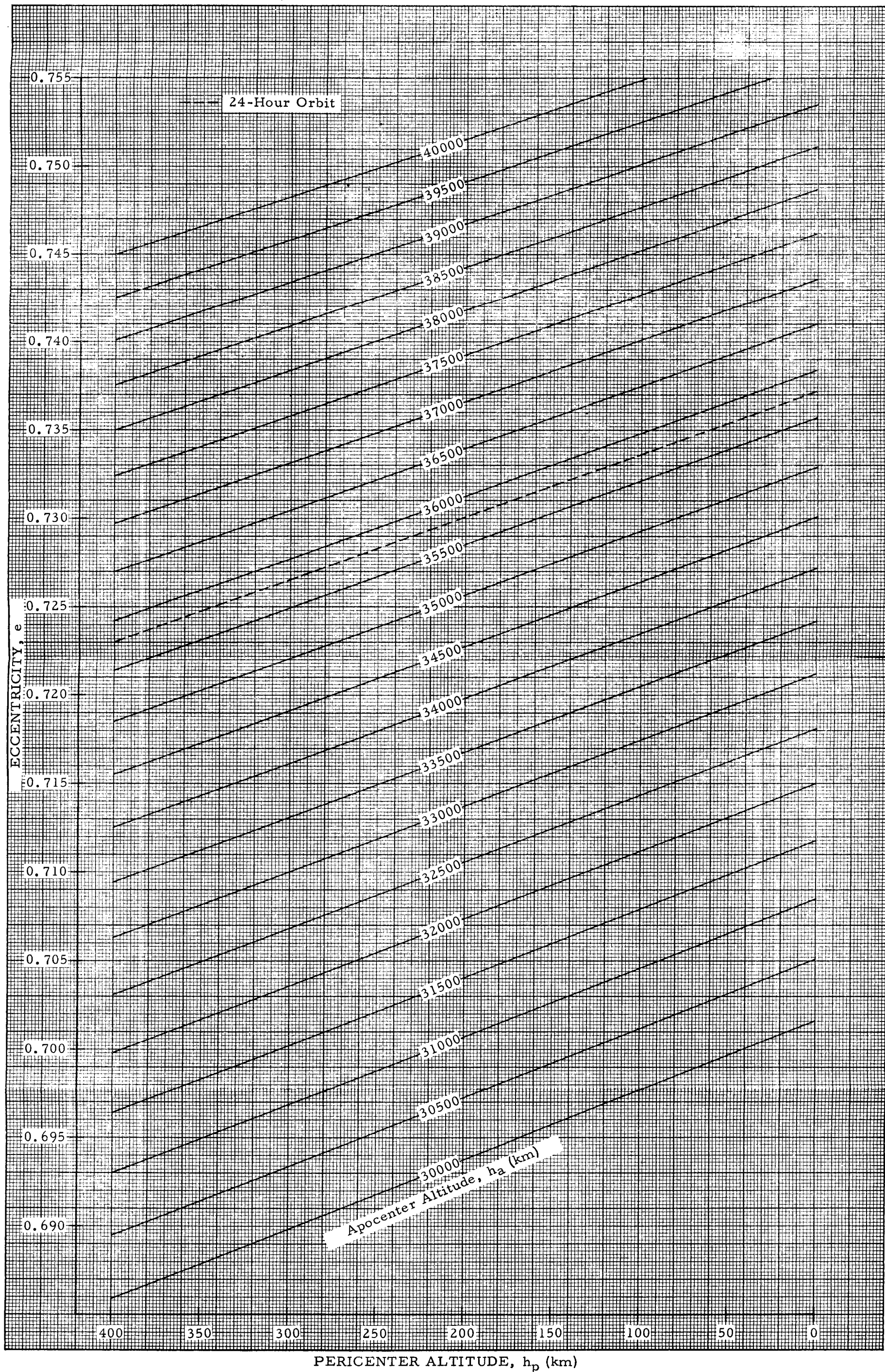


FIGURE 4d. ECCENTRICITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

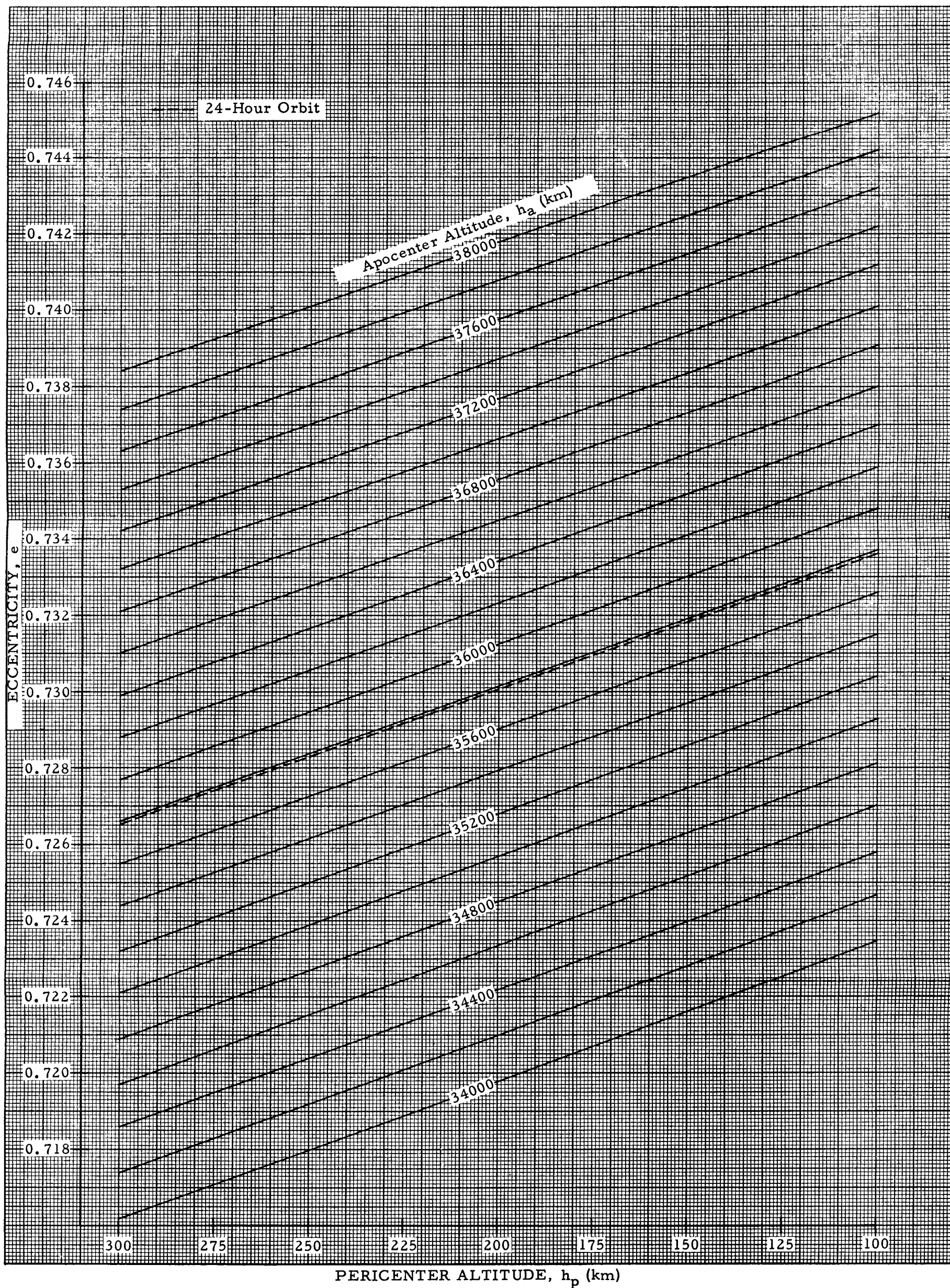


FIGURE 4e. ECCENTRICITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

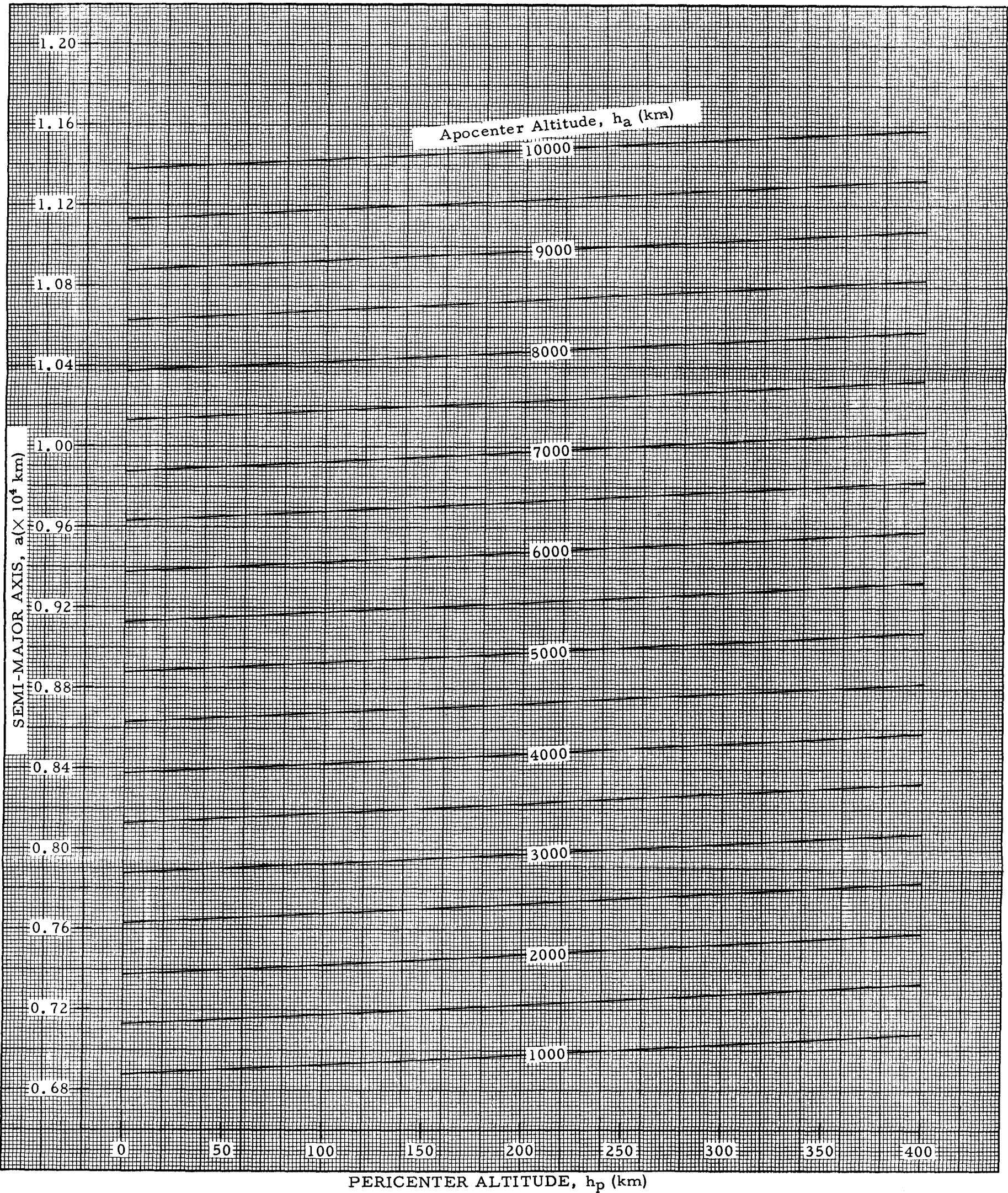


FIGURE 5a. SEMI-MAJOR AXIS VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

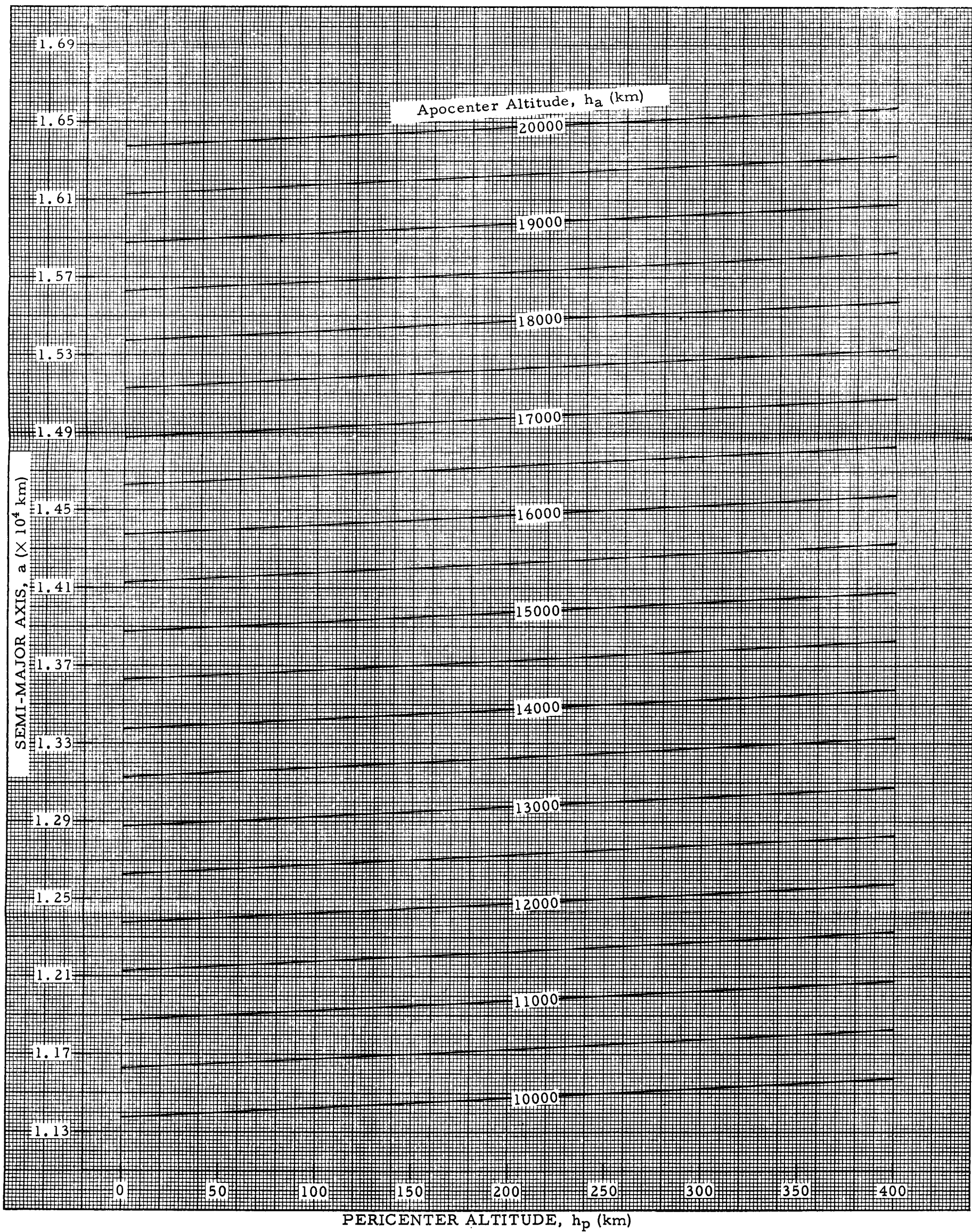


FIGURE 5b. SEMI-MAJOR AXIS VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

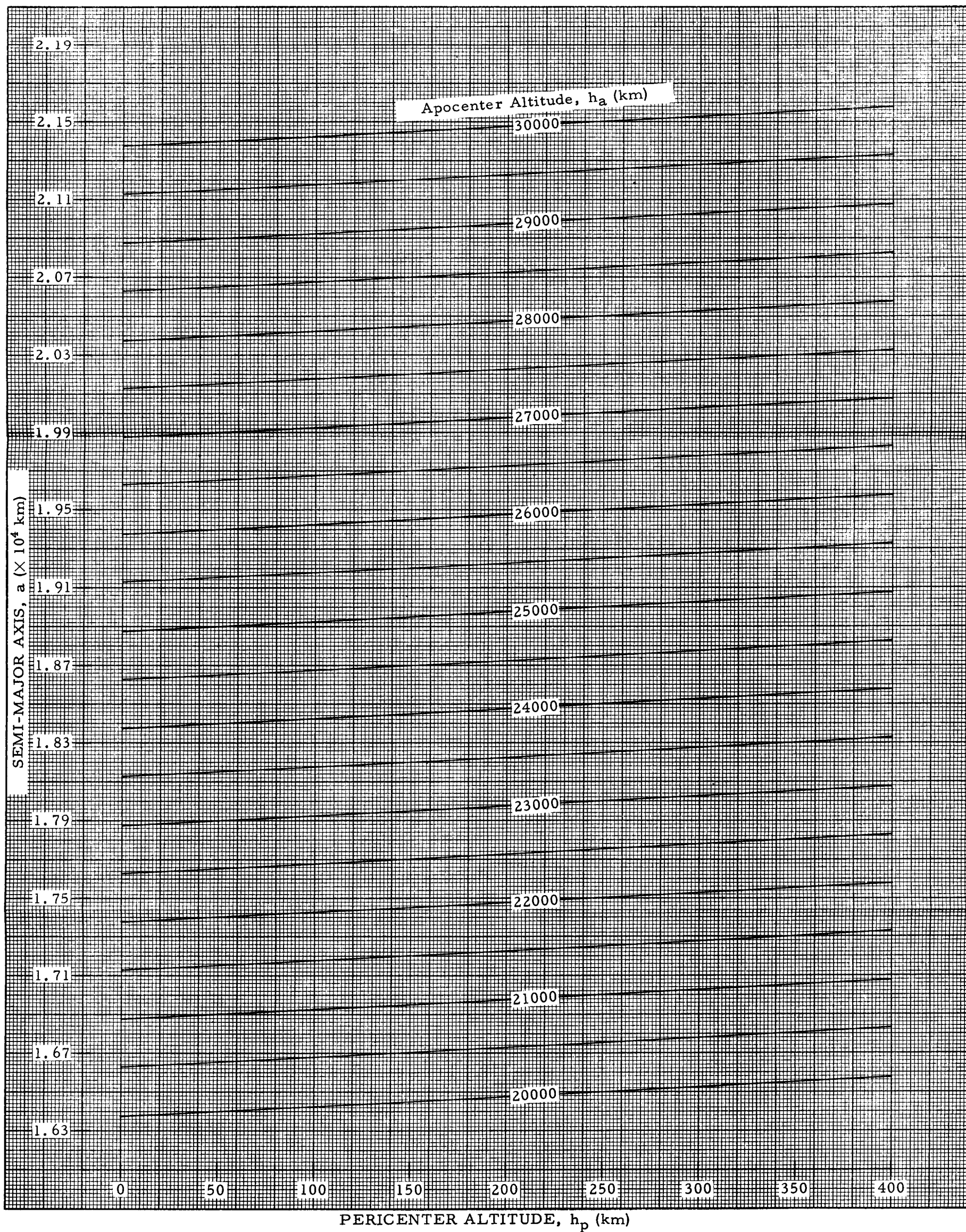


FIGURE 5c. SEMI-MAJOR AXIS VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

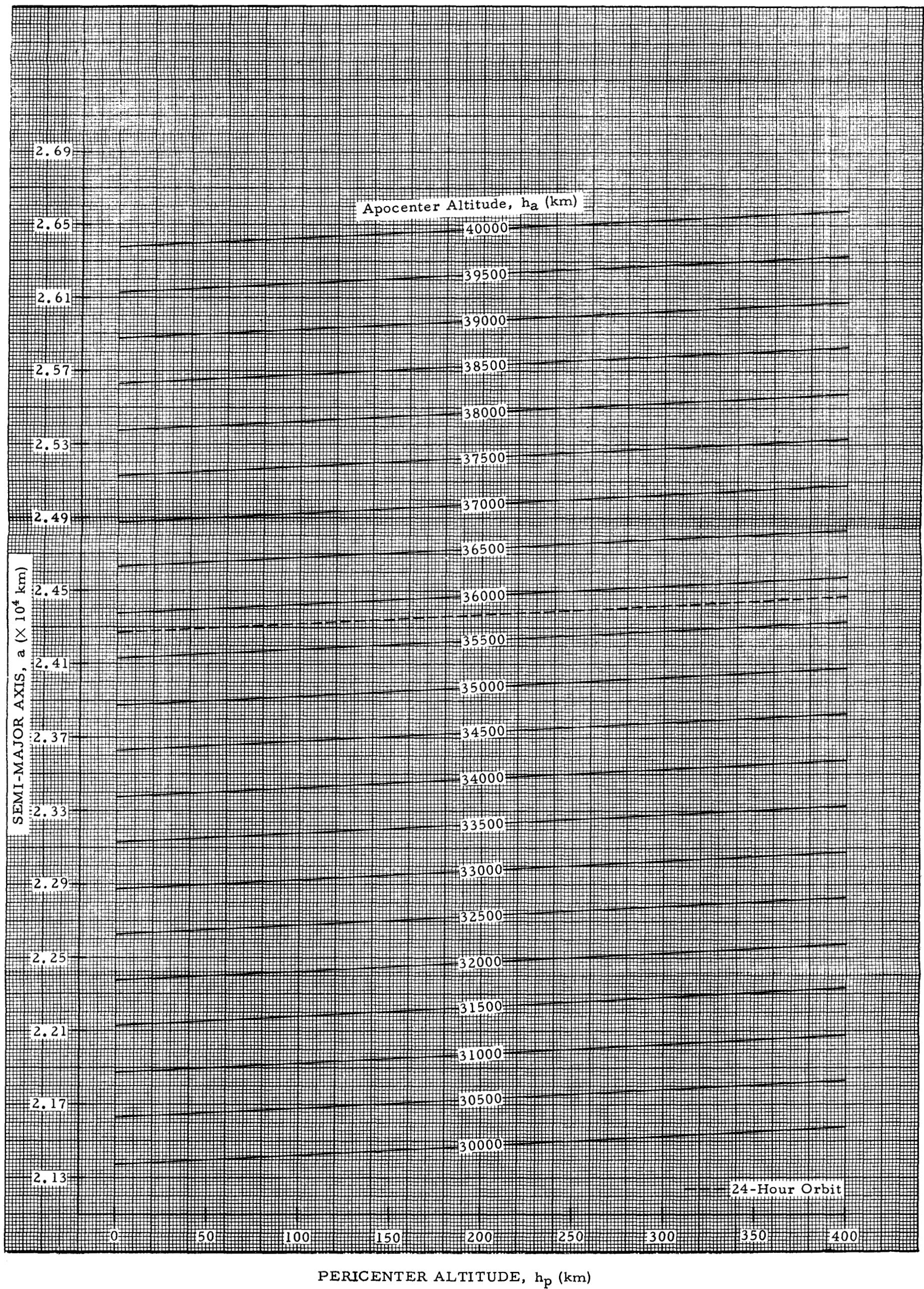


FIGURE 5d. SEMI-MAJOR AXIS VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

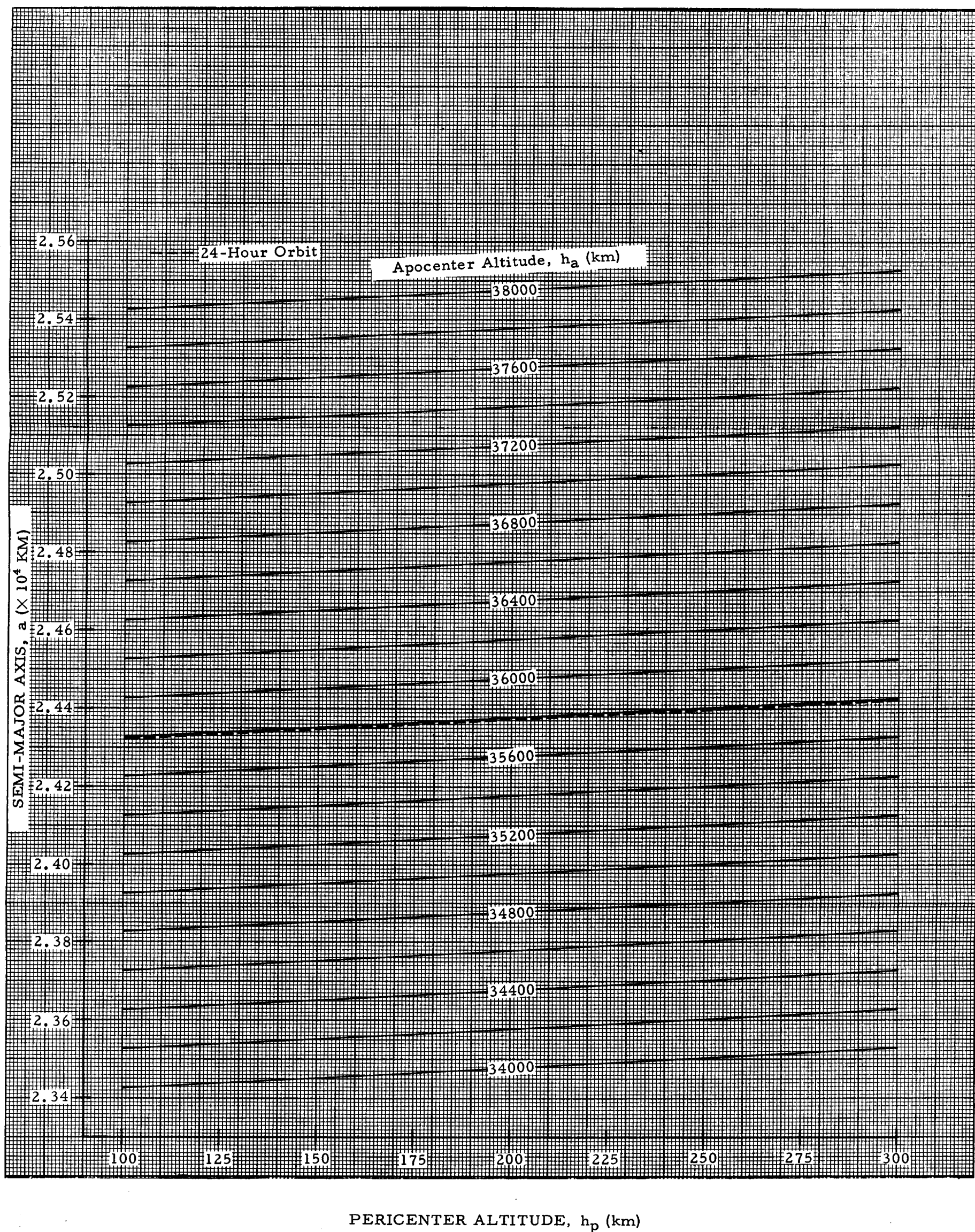


FIGURE 5e. SEMI-MAJOR AXIS VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

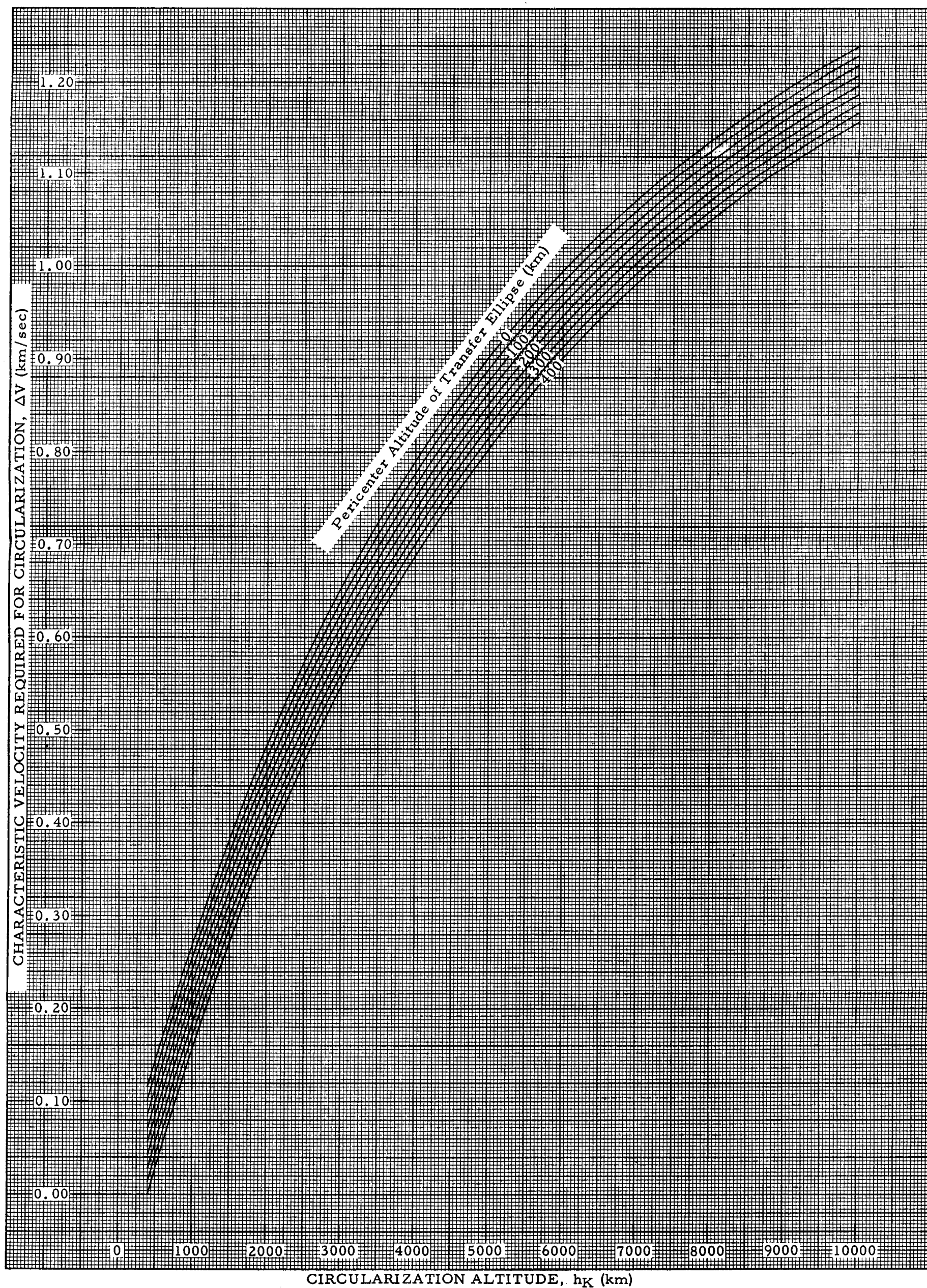


FIGURE 6a. THE CHARACTERISTIC VELOCITY REQUIRED FOR CIRCULARIZATION VERSUS CIRCULARIZATION ALTITUDE WITH PERICENTER ALTITUDE OF THE TRANSFER ELLIPSE AS A PARAMETER

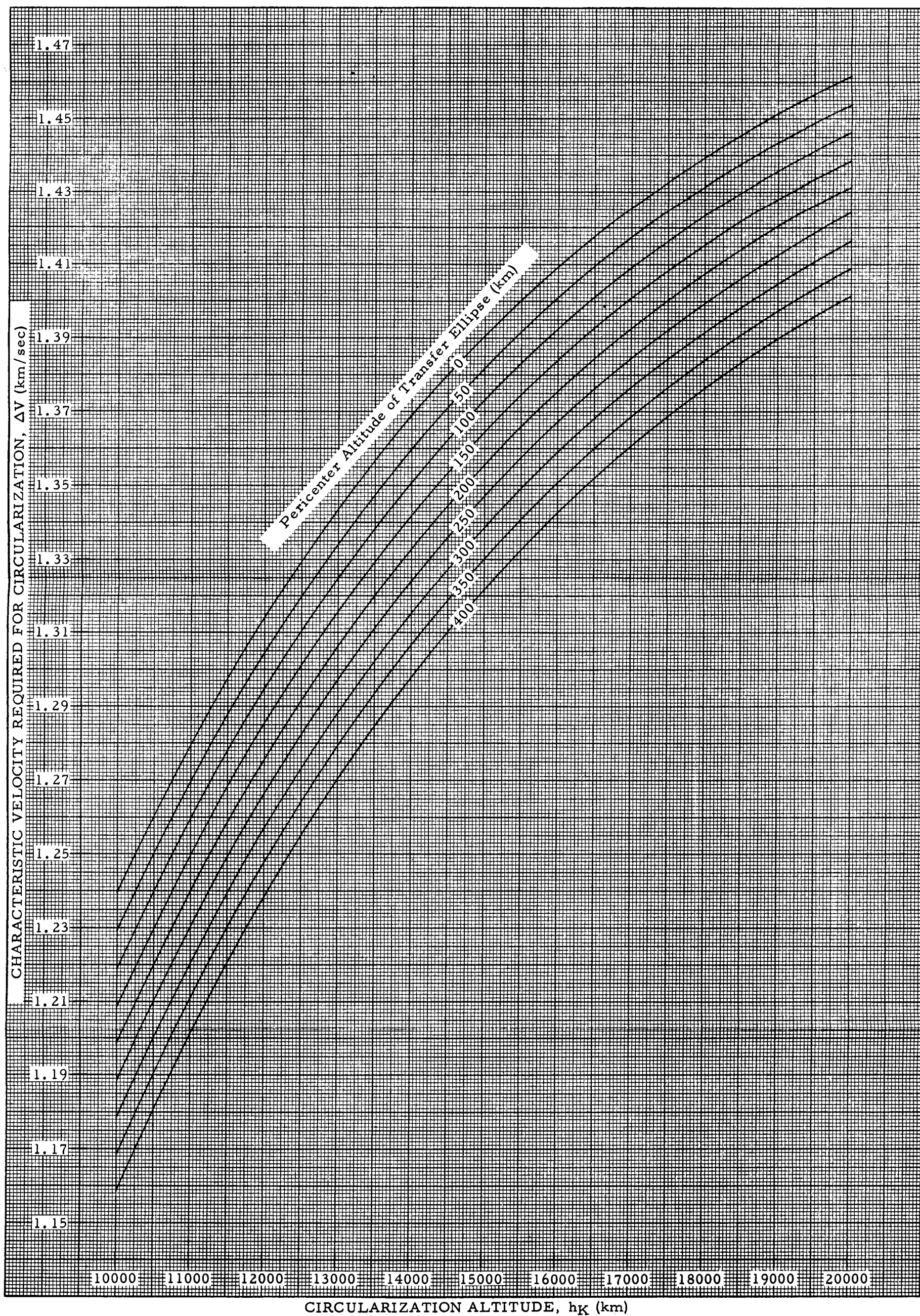


FIGURE 6b. THE CHARACTERISTIC VELOCITY REQUIRED FOR CIRCULARIZATION VERSUS CIRCULARIZATION ALTITUDE WITH PERICENTER ALTITUDE OF THE TRANSFER ELLIPSE AS A PARAMETER

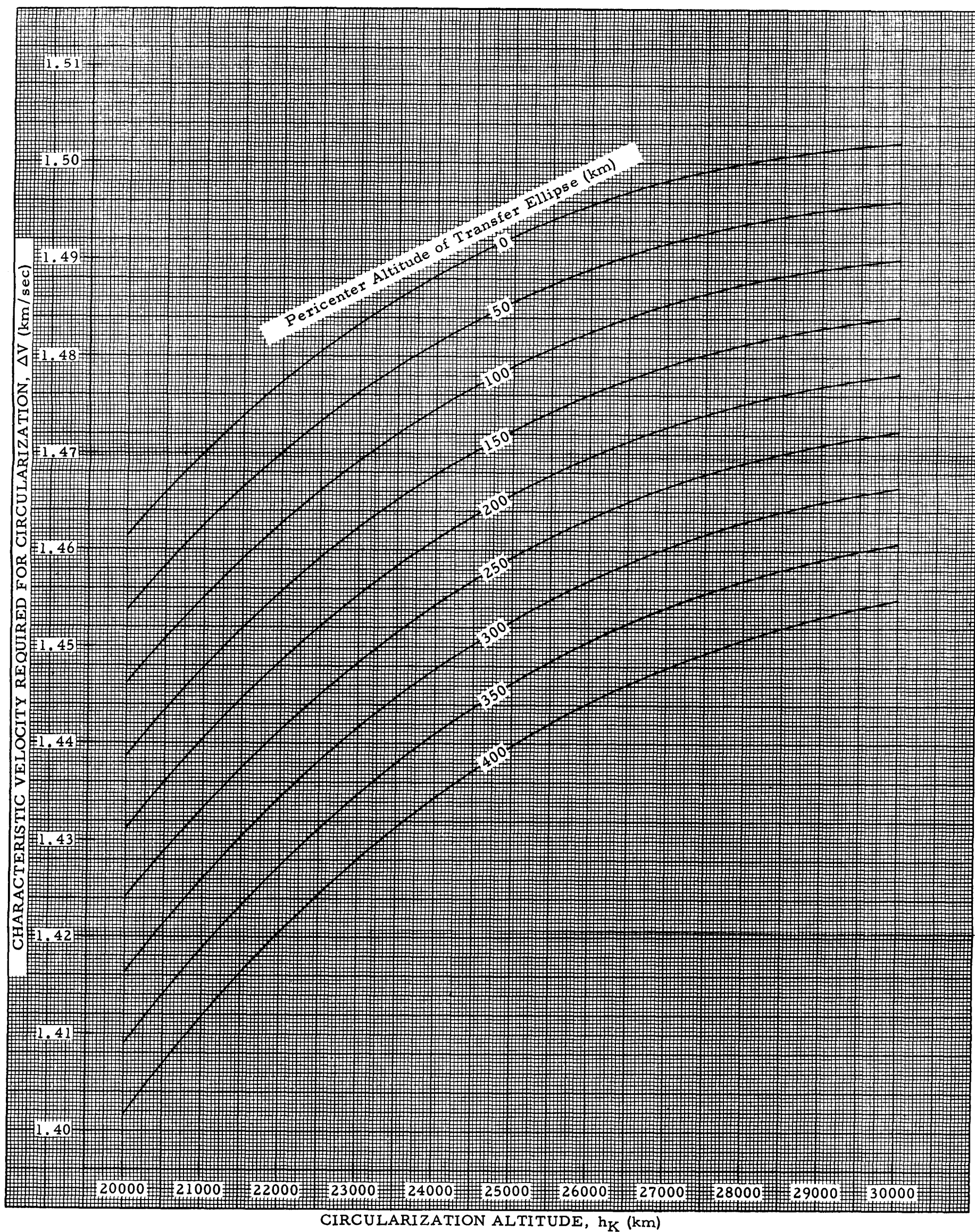


FIGURE 6c. THE CHARACTERISTIC VELOCITY REQUIRED FOR CIRCULARIZATION VERSUS CIRCULARIZATION ALTITUDE WITH PERICENTER ALTITUDE OF THE TRANSFER ELLIPSE AS A PARAMETER

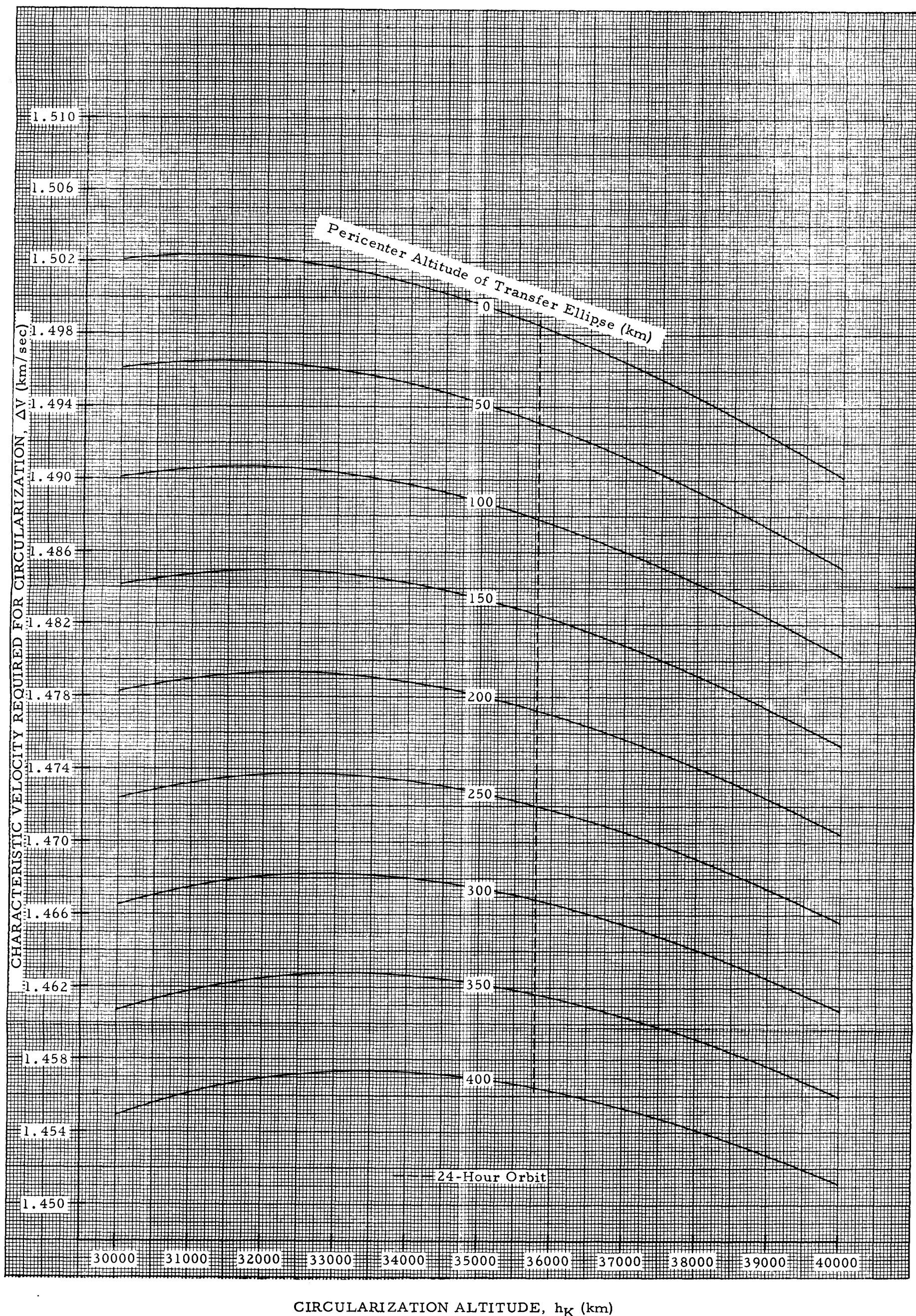


FIGURE 6d. THE CHARACTERISTIC VELOCITY REQUIRED FOR CIRCULARIZATION VERSUS CIRCULARIZATION ALTITUDE WITH PERICENTER ALTITUDE OF THE TRANSFER ELLIPSE AS A PARAMETER

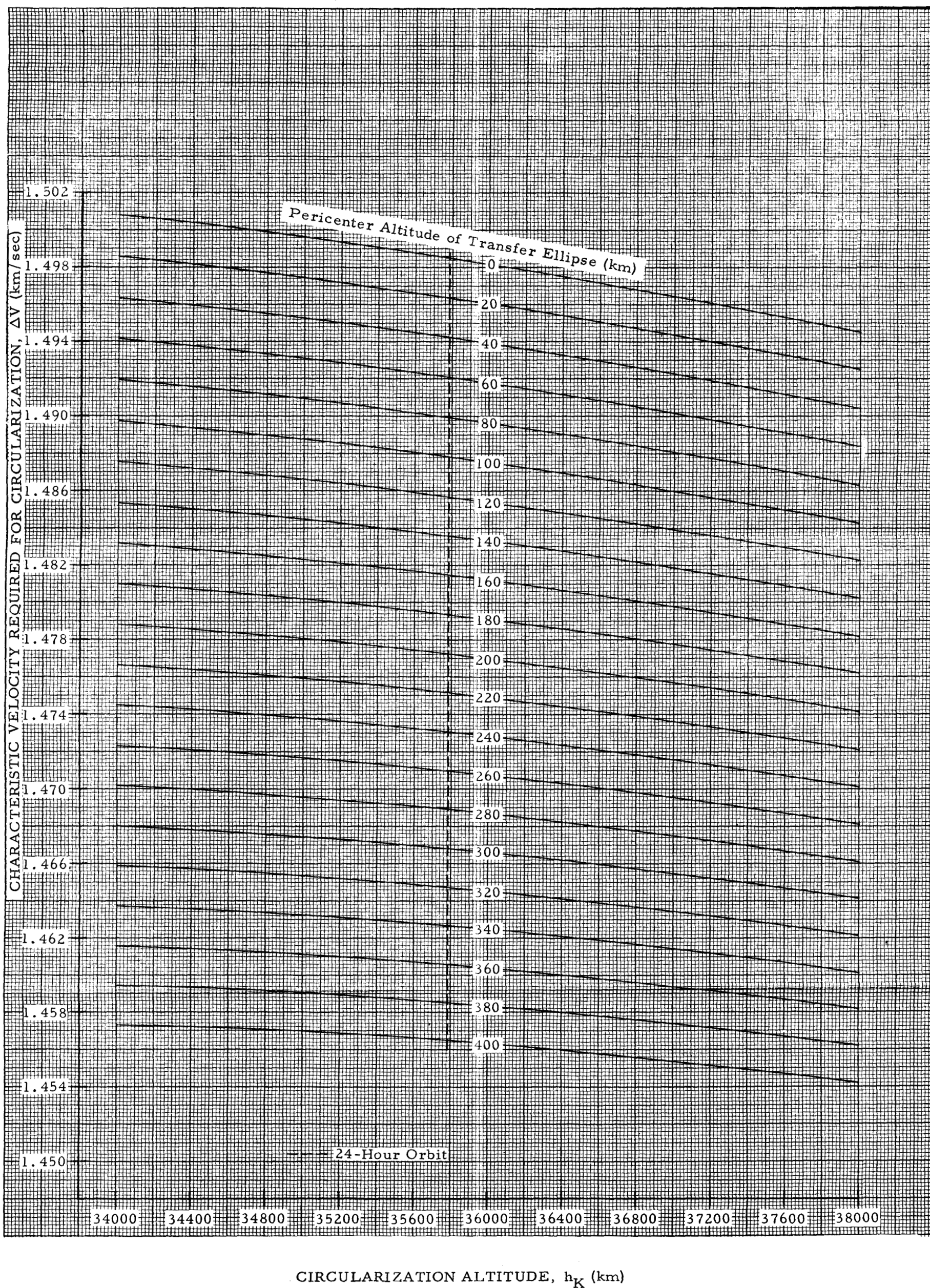


FIGURE 6e. THE CHARACTERISTIC VELOCITY REQUIRED FOR CIRCULARIZATION VERSUS CIRCULARIZATION ALTITUDE WITH PERICENTER ALTITUDE OF THE TRANSFER ELLIPSE AS A PARAMETER

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August 29, 1963

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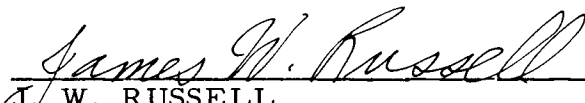
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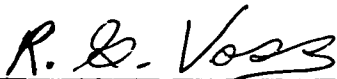
ORBITAL PARAMETERS FOR ARTIFICIAL EARTH
SATELLITES UP TO 40,000 KM ALTITUDE

By

Walter H. Stafford
Sam H. Harlin
Carmen R. Catalfamo

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